



**A Comparison of EEG and Evoked Response  
Data Collected in a UH-1 Helicopter to  
Data Collected in a Standard  
Laboratory Environment**

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Aircrew Health and Performance Division

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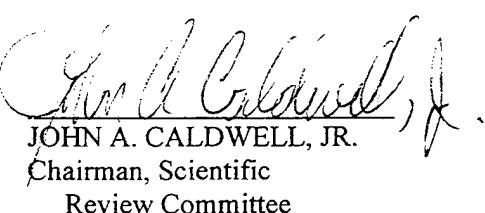
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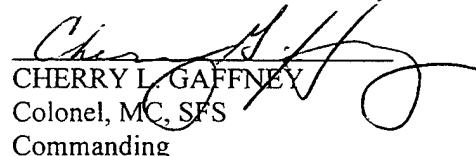


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USAARL Report No. 97-30 "A Comparison of EEG and Evoked Response Data Collected in a UH-1 Helicopter to Data Collected in a Standard Laboratory Environment" by

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The present investigation was designed to verify indications from a small, previously conducted USAARL investigation that useable spontaneous EEG recordings could be made from			
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helicopter pilots in flight. In addition, this study examined the feasibility of recording and telemetering cortical evoked potentials from subjects flying a UH-1 helicopter.

Twenty subjects (10 aviators and 10 nonaviators) were tested both in the laboratory and in the aircraft. Spontaneous EEGs were collected once during eyes-open and eyes-closed conditions on the ground and once again in the air. Cortical evoked responses (P300s) were collected once on the ground and twice in the air (initially after takeoff and prior to flying an instrument approach). The pilots remained "on the controls" during the collection of the second in-flight P300.

Results confirmed indications from an earlier investigation that it was feasible to collect and telemeter valid spontaneous EEG activity from personnel flying onboard a UH-1 helicopter. In addition, there was substantial evidence that it was possible to perform in-flight auditory P300 monitoring on both pilots and nonpilots. Although the quality of the EEG recordings from the aircraft is not as high as similar recordings made in the laboratory, careful visual epoch screening (in which movement artifacts are avoided) and automated artifact rejection algorithms (applied to the P300 data) resulted in valid outcome measures. A follow-on study will examine the utility of monitoring the EEG activity of aviators during actual in-flight, on-the-controls segments.

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## Background

### Military relevance

Aviators frequently must perform their duties for extended durations under less than optimal conditions. Because it is not always possible for personnel to receive "time off" from operational tasks, pilots may face continuous duty days which persist beyond the normal 8 hours, particularly during periods of high workload and especially during combat. In addition, there are scenarios in which aviators, while not being required to work excessive numbers of hours, are expected to perform effectively under very stressful flight conditions. For instance, a pilot may receive flight taskings despite the presence of sleep deprivation which compromises judgement and alertness. Also, aviators must be prepared to operate aircraft under emergency situations in which one or more aircraft systems have failed, or they must assume both pilot and copilot duties which substantially increases the level of flight task demands.

During these situations, personnel safety and mission effectiveness may be compromised as a result of mental fatigue, physical fatigue, or other factors. Generally, as long as the aviator is still on the ground, it is left to the commander or flight surgeon to make a subjective evaluation of aviator status and render a "go" or "no-go" decision about that individual. However, aviators in flight are left on their own to make "go/no-go" decisions. Although many commanders, physicians, and pilots are comfortable with this decision-making process, there is variability in the criteria used by different persons and, as a result, there is a high degree of liability assumed by these individuals in the event that a mishap occurs. In addition, there are particular problems associated with relying on individual aviators to judge their own performance capabilities simply because the judgement of a stressed or fatigued individual is likely to be significantly impaired.

As a result of these difficulties, the operational and medical communities have expressed interest in the development and validation of more objective measures of aviator status which may help to make important decisions about crew endurance and crew safety. Both preflight and in-flight assessment techniques are needed, and the present study will focus on the latter. Once it is established that real-time, in-flight assessments of aviator status are possible, the development and refinement of computerized safety networks to predict (and thus avoid) pilot degradation and incapacitation will be within the realm of possibility.

### Assessment methodologies

Numerous techniques for assessing individual status exist. One popular approach uses either paper-and-pencil or computerized cognitive tests to assess various mechanisms of human information processing (AGARD, 1989). The underlying assumption of this approach is that anything which affects these basic mechanisms will produce an effect on tasks where such functions or mechanisms are required. The results from cognitive tests are used to predict operational performance problems as a function of stress or fatigue.

Another approach emphasizes the use of job-related performance assessments such as the measurement of a pilot's ability to control an aircraft or simulator (Dellinger, Taylor, and Richardson, 1986; Simmons et al., 1989; Lees and Ellingstad, 1990; and Caldwell et al., 1991). In this case, actual performance on specific job skills is measured (i.e., ability to control airspeed and altitude) and the result is used to document and predict operational performance problems.

Unfortunately, these approaches to assessing the potential for performance decrements are limited in at least two respects. First, with regard to the cognitive assessments, it is often not possible to safely interrupt primary task performance (i.e., flying the aircraft) in order to administer any type of test. Thus, these types of assessments can only be conducted before or after the performance period (i.e., a flight), and this introduces problems with the timeliness of the assessments. Secondly, with regard to the on-task performance assessments (measuring flight skill), it is often difficult to determine the acceptability of performance fluctuations using automated scoring techniques. There are situations in which rapid altitude or heading changes may be required in order to ensure mission accomplishment or survival, but a scoring system (for instance, one implemented on computer) may interpret these rapid changes as indicative of an impaired pilot. Thus, in order for such assessment schemes to work as intended, there must be a concurrent assessment of the individual aviator's status. Some authors (Caldwell et al., 1993) have suggested that psychophysiological assessment techniques will fill the void left by more typical performance-based evaluations of pilot status.

It is necessary to identify a method for assessing the operational status of individual aviators which overcomes the problems that exist with standard performance testing algorithms. Specifically, there is need for an approach which 1) can be conducted during the accomplishment of the operational task (flight); 2) is feasible from an equipment and personnel perspective; and 3) is objective, reliable, and valid. One type of measure which appears to be a reasonable candidate for an assessment technique which would satisfy all three of these basic concerns is one that directly measures aviator status via assessments of psychophysiological variables.

Of the physiological measures available for use, the electroencephalogram (EEG) appears to be the most direct measure of central nervous system (CNS) functioning. However, the advantages of EEG in terms of its direct reflection of CNS neural and presumably "cognitive" activation are somewhat offset by the disadvantages in terms of data collection and analysis difficulties. Particularly in the past, there have been substantial instrumentation difficulties which have discouraged attempts to collect EEG from subjects in actual aircraft. Recently, however, there has been a resurgence of interest in examining the electrical activity of the brain during various operational scenarios, and it appears that many of the instrumentation problems have been overcome.

#### EEG/EPs collected in flight

EEGs have been collected during both simulator and actual flights in the fixed wing environment, and attempts have been made to directly relate EEG activity to performance

accuracy on operational tasks. Sem-Jacobsen et al. (1959) reported the feasibility of obtaining 8-channel EEG recordings from both pilots and nonpilots in a T-33 jet during operational flight. Later, Sem-Jacobsen (1961) reported success utilizing in-flight EEG analysis in combination with in-flight motion pictures to aid in the selection of pilots for high-performance aircraft. Other authors (LaFontaine and Medvedeff, 1966; Maulsby, 1966; Howitt et al., 1978; and Wilson et al., 1987) have offered further evidence for the utility of using EEG as a measure during flights. Sterman et al. (1987) recorded several channels of EEG from pilots flying fixed wing aircraft and simulators, and the data were analyzed offline following flights. The results suggested that EEG activity distribution may be associated with pilot performance. Specifically, these authors found asymmetries between the centrally-recorded alpha EEG activity from the left and right hemispheres of pilots engaged in competent performance (the activity in the left hemisphere was greater than the activity in the right). In addition, Sterman et al. (1987) reported bilateral increases in theta activity (4-7 Hz) and decreases in alpha activity (8-11 Hz) recorded from the sensorimotor and visual cortex in response to increasing cockpit workloads (with some associated G-force effects). Wilson et al. (1994) partially confirmed these workload effects in a study which showed that parietal theta activity increased as a function of cognitive demand when pilots were flying several maneuvers in a fixed wing aircraft. Offline analysis of EEG data showed increases in theta across maneuvers that were subjectively judged to require the most mental effort of the maneuvers flown.

Based on these findings, it appears feasible to evaluate the spontaneous cortical activity from fixed wing pilots and to obtain useful information about workload (and possibly pilot status) from these evaluations. Unfortunately, however, there has been little work performed on the feasibility of collecting EEG data from rotary-wing pilots, and few studies have examined the potential of using real-time telemetered EEGs as opposed to recorded EEGs. Furthermore, whereas Wilson et al. (1994) have explored the acquisition and analysis of cortical evoked response data as a workload indicator in fixed wing pilots, a similar study has not been conducted in helicopters. Follow-on studies in helicopters are critical due to the fact that noise, vibration, and other environmental stressors tend to be greater in rotary-wing than in fixed wing aircraft.

A recently conducted small investigation by Caldwell et al. (1994) suggested that it was feasible to collect and telemeter 21 channels of spontaneous EEG from helicopter pilots in flight. However, the in-flight EEGs were recorded only during resting conditions (with a safety pilot "on the controls") and not during maneuvers in which the subject was flying the helicopter. Thus, there was no indication as to whether or not telemetered EEGs could provide an indication of pilot workload. Also, relatively few test subjects were examined in this earlier study, so a replication of the results was necessary to prove consistency across different samples. Finally, there was no attempt to collect and evaluate cortical evoked response data in this first evaluation of helicopter pilots in flight.

## **Real-time telemetry of spontaneous and evoked brain electrical activity**

There exists a need to expand upon the work of earlier research which has focused primarily on collecting and analyzing spontaneous EEG data in the fixed wing environment and evoked response data in the laboratory. Before attempting to predict or evaluate flight performance decrements using these types of measures, both types of data, collected with a full 10-20 electrode montage, should be compared across the laboratory and in-flight environments, and a feasibility assessment should be performed in which in-flight EEGs are collected from both resting and working pilots. In addition, a full 10-20 montage of electrodes should be used to permit a complete assessment of the brain's electrical activity from every standard recording site. This has the potential of significantly enhancing the sensitivity (and the predictive validity) of data because activity from the entire cortical surface can be examined--thus avoiding the potential that noteworthy changes in brain activity may be overlooked simply because the "wrong" recording site is chosen.

### **Objectives**

The present investigation is designed to 1) verify indications from a smaller, earlier study, that useable spontaneous EEG recordings can be made from helicopter pilots in flight; and 2) establish the feasibility of recording and telemetering cortical evoked potentials from subjects flying in a utility helicopter. A follow-on study will address the issue of whether EEGs collected during the performance of actual flight maneuvers can yield useful information about pilot workload. These investigations should help establish the methodology for making real-time in-flight assessments of the effects of workload, stress, and fatigue attributable to a variety of operationally-relevant stressors.

### **Methods**

#### **Subjects**

Twenty subjects were recruited for this study. Ten were UH-1 qualified aviators, and 10 were nonaviators. The average age of the aviators was 31.0 years (ranging from 25-47), and the average age of the nonaviators was 28.5 years (ranging from 23-36). Three of the 20 subjects were females. During testing, the aviators were seated in the front right seat of the aircraft in close proximity to flight instruments. They were tested under resting conditions and during times at which they were actively involved in certain flight tasks. Nonaviators were seated in the back of the aircraft, away from several potential sources of electronic interference, and they remained passive throughout the entire flight.

## Apparatus

EEG assessments were conducted in both the standard laboratory environment and the in-flight environment. The systems used for each type of assessment are described below.

### Laboratory assessments

Laboratory electroencephalographic evaluations were conducted using a standard, commercially available Cadwell Spectrum 32. This device is equipped with the necessary hardware and software to collect, store, and analyze lengthy EEG records from subjects tested in a standard laboratory environment. In addition, this device is equipped with an auditory simulation unit for delivery of the tones presented in the auditory P300 via etymotic earphones. All EEG and evoked response data were recorded on optical disk for later review and analyses. Data were collected with the widest filter settings available on the Spectrum 32 in order not to obscure any useful information discernable from initial visual examinations of the traces or from subsequent power spectral analyses. The high filter was set at 100 Hz and the low filter was set at 0.53 Hz. The EEG traces (hard-copy displays) were produced with a standard sensitivity of 50 microvolts per centimeter with a paper speed of 30 millimeters per second. The P300 traces were produced with a sensitivity of 12.5 microvolts per division with a total time window of 750 milliseconds. Several of these traces are displayed later in this report (see appendices A and B).

### In-flight assessments

In-flight electroencephalographic evaluations were conducted with a Cadwell Airborne Spectrum 32 set to the parameters discussed above. This device was mounted in a UH-1 utility helicopter (see figure 1) where it was interfaced with the telemetry equipment described below.



Figure 1. The UH-1 aircraft in which in-flight testing was conducted.

### Airborne unit

The Airborne Spectrum 32 uses three microprocessors--one for acquisition, one for data transmission, and one for supervision. Booting the computer loads all software from a battery-backed RAM-disk board and puts the system in a mode where it waits for linking and subsequent commands from the ground station Spectrum 32. The unit is shock-mounted in an aluminum cage, mounted to the cabin floor behind the pilot's seat (see figure 2). The overall weight of the unit is approximately 75 pounds. Power comes from the aircraft 28-volt DC bus.

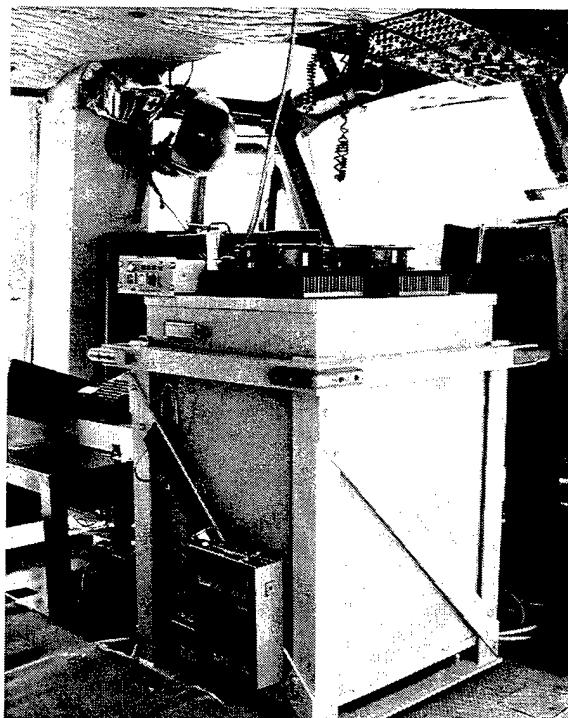


Figure 2. The airborne Spectrum 32.

Software in the airborne unit is a subset of the standard Spectrum 32 software. It can acquire signals, but it has no graphics display capability. Specialized software was developed to handle commands received from the ground station and the transmission of data to it. All data acquired are placed into a first-in, first-out "ring buffer," where it waits for transmission to the ground unit. This buffer is designed to hold data during periods where the telemetry radio link is lost, as in steep turns or very low-level flight. Depending on certain factors (such as the number of EEG channels being collected), this buffer can store several minutes of data. When collecting 19 channels of EEG, 6 minutes of data can be buffered in the event of transmission interruption.

Once digitized by the acquisition processor, the data are grouped into blocks by the communications processor, for transmission to the ground Spectrum. The signal output from the

airborne unit is a serial bit stream at a rate of 100 kHz. This signal is lo-pass filtered to reduce the bandwidth requirements of the radio link to approximately 150 kHz. High and low levels, similar to the NRZ-L format used in pulse code modulation telemetry systems, are used to represent 1's and 0's.

Commands sent up to the airborne unit are also in a digital format, like the data. The uplink bit rate is somewhat slower, however, at 60 kHz. Received by the telemetry receiver, this serial stream is first routed through the UART card of the airborne unit where it is both hi- and lo-pass filtered, and converted to a parallel form. The communications processor on the link board then buffers these commands until the main processor is ready to execute them.

#### Ground unit

The ground unit is a Cadwell Spectrum 32 (see figure 3) which contains the usual Spectrum 32 hardware with two additional circuit boards installed in the computer's AT backplane. One board, called the UART board, conditions the incoming signal from the receiver, shapes the outgoing signal to the transmitter, and does the serial-to-parallel conversions for both directions. The second board, the link controller, contains the communications processor and buffers, where outgoing data are held until ready for transmission, and incoming data are held until ready for processing by the rest of the system. Incoming data from the aircraft are displayed on the ground Spectrum's text and graphics monitors and stored on an optical storage disk.

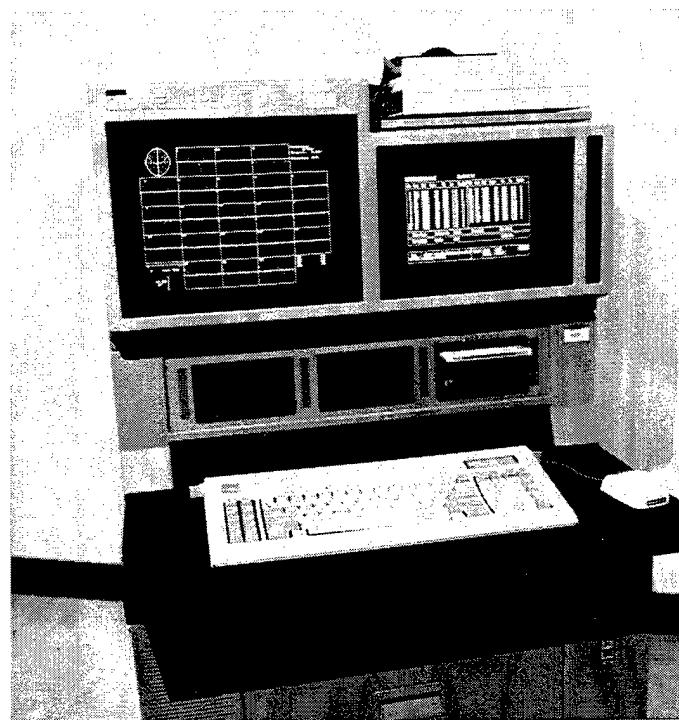


Figure 3. The ground-based Spectrum 32.

Special software is used by the ground unit to communicate with the airborne unit. Though much of the software appears similar to that of a normal Spectrum, it has differences to account for the communication link between the ground and airborne units. The operator still has the same testing features available and can bring up screens for impedance checks, preamplifier calibration, etc. The data display is different from what is normally seen on a standard Spectrum 32. Rather than the typical continuous streams of data, similar to a standard EEG paper trace, the data are presented in 8-second blocks (or 1 "page" at a time). Data transferred from the airborne unit come in groups of small packets. Integrity is assured by using a checksum scheme and "handshaking" with each data group. For each packet sent by the airborne unit, the ground unit returns an acknowledgement. If a packet is not acknowledged by the ground unit, it is re-sent. Packets are time-stamped to aid in reconstructing the original data signals.

Commands to be transmitted to the airborne unit are generated by the main processor and handed off to the communications processor on the link board. When ready, the command is converted to a serial stream and is low-pass filtered as mentioned above. Data signals from the airborne unit are received by the telemetry receiver, and are first routed through the UART card of the ground unit where they are both high- and low-pass filtered, and converted to a parallel form. The communications processor on the link board then buffers these data until the main processor is ready for display or storage.

#### Radio link

The telemetry system uses a two-way microwave radio link to send commands from the ground station up to the aircraft ("uplink") and EEG data signals from the aircraft down to the ground station ("downlink"). Operating at 1740 MHz, the uplink is composed of a transmitter at the ground station and a matching receiver in the aircraft, and one antenna at each location. The downlink, operating at 1820 MHz, consists of a transmitter mounted in the aircraft and a matching receiver located at the ground station. It shares the same antennas with the uplink by the use of two diplexers. The ground-based telemetry station is depicted in figure 4.

The specific components used in the aircraft include a Broadcast Microwave Services (BMS) model TBT-20015SV transmitter mounted in the right aft compartment, and a BMS portable receiver, model TBR-300, located in the left aft compartment. Power for the transmitter and receiver units comes from the aircraft 28-volt DC bus through a 10-amp circuit breaker installed in the overhead control panel. A K&L model 4CZ45-1740/NT1820-N/N diplexer is used to feed the transmitter and receiver cables into a common omnidirectional antenna, a BMS model TBA-2-0, which is mounted to the lower side of the tail boom.

At the ground station, an Anixter Communications Systems model P-1548GN dish antenna is mounted on a Tecom Industries model 203011A controller and model 203009 rotator system. This azimuth-only system allows the aircraft to be tracked during flight testing. The antenna is connected through a diplexer--as on the aircraft--to the transmitter and receiver. The transmitter

and diplexer used at the ground station are identical to those in the aircraft. A Loral Terracom model TCM-601A receiver provides the down-link data signal to the ground-based Spectrum 32.



Figure 4. The laboratory-based telemetry station with radio transmitter and receiver, antenna tracking controller, oscilloscope, and Cadwell Spectrum 32 equipped with special circuit boards.

Though other systems would certainly work, this telemetry system proved successful in transmitting and receiving the Spectrum signals over a range of approximately 40 miles when the aircraft was approximately 1000 feet or more above ground level. Its use was dictated by the fact that this equipment was "on-hand," and the proper frequency authorizations were available.

#### Auditory stimuli for the P300

Since subjects were required to complete auditory P300s in the aircraft, special provisions were made for delivering audible tones without compromising safety (i.e., subjects could not be required to remove their flight helmets). Auditory stimuli were presented to the subjects' helmet-mounted headset via a locally-constructed interface unit which served as a junction box for the aircraft communications system and the Cadwell auditory stimulation unit. Prior to initiating the P300, a selector switch was rotated so that the subject was prevented from hearing radio or crew communications, but instead was able to listen exclusively to the tones generated from the Cadwell stimulator. In order to compensate for the high levels of noise present during in-flight

assessments, the locally-constructed interface unit also amplified the auditory stimuli by a factor of 20.

#### Recording electrodes for EEGs and evoked responses

Grass silver cup electrodes, placed on subjects' scalps with collodion, were used to detect EEG signals. These are the standard Grass E5SH electrodes used in typical clinical settings. No modifications to the electrodes or wiring were made.

#### Procedure

Each subject was tested twice during a single day (once in the laboratory and once in flight). The testing order was counterbalanced within each group (pilots and nonpilots) so that an equal number of subjects from each group were tested in both orders (laboratory-then-aircraft versus aircraft-then-laboratory). Upon arrival at the laboratory, 25 EEG scalp placements were measured, marked, and cleaned with acetone. After each site was thoroughly cleaned, electrodes were attached to the scalp with collodion, and each electrode was filled with electrolyte gel (SignaGel). Impedances were reduced to 5000 ohms or less prior to testing.

#### Laboratory testing for pilots and nonpilots

Following electrode application, each subject proceeded to his/her first EEG test (in the laboratory or the aircraft, depending on the counterbalanced scheme). The laboratory testing for aviators and nonaviators was identical. During the laboratory test, the subject was seated in a relatively quiet area where he/she was connected to the ground-based Spectrum 32. After impedances were checked, the subject was instructed to sit quietly for 5 minutes with eyes open followed by 5 minutes with eyes closed. Then, each subject completed an auditory P300 (using 70 dB stimuli). These tests are described in more detail below. After the subject completed the laboratory tests, he/she was escorted to the aircraft for airborne testing.

#### In-flight testing for pilots

The flight test for aviators consisted of the pilot being seated in the right seat of the UH-1 where he/she was connected to the EEG preamplifier. Prior to departing from the pad in front of the Laboratory, impedances of electrodes and the integrity of the radio link (between ground-based and Airborne Spectrum) were checked, and adjustments were made as appropriate to guarantee the quality of the data.

A USAARL safety pilot conducted each flight in the UH-1, but the test aviator was required to fly the aircraft and complete a profile of upper airwork flight maneuvers lasting approximately 1 hour (see table 1). The flight profile began at an altitude of 1500 feet mean sea level (MSL). The subject flew all of the specified maneuvers under command from the safety pilot. The same sequence of maneuvers was used for every subject.

Shortly after takeoff, but prior to the beginning of the standardized flight profile, aviators completed an eyes-open/eyes-closed EEG (approximately 5 minutes of each) and an auditory P300 while the safety pilot flew the helicopter. During the resting eyes-open EEG, subjects were told to focus on a fixed point in order to minimize eye movements while data were collected. In the event that the signal was contaminated with artifact, subjects were instructed via radio link from the ground-based receiving station to correct the problem (i.e., minimize eye movements, relax jaw muscles, etc.). Actual data collection continued until approximately 5 minutes of useable data were stored on optical disk for later spectral analysis. Next, subjects were instructed to close their eyes while another 5 minutes of resting EEG data were recorded. Once again, artifact-contamination problems were eliminated as much as possible during actual data collection. Following the resting EEG, subjects completed an auditory P300 task in which they were presented with a series of high-pitched (2000 Hz) and low-pitched (500 Hz) tones delivered via the helmet audio system. Subjects were instructed to count the number of high pitched tones. Of the total of 200 tones, presented at a rate of approximately 1 every 0.9 seconds, 40 were high tones and 160 were low tones.

Table 1.  
Flight profile.

1. Standard rate 360 degree right turn
2. Straight and level number 1 (2 minutes)
3. Standard rate 360 degree left turn
4. Straight and level number 2 (2 minutes)
5. Climb 1000 feet at 500 feet per minute
6. Steep (30 deg. bank) 720 degree left turn
7. Straight and level number 3 (2 minutes)
8. Steep (30 deg. bank) 720 degree right turn
9. Straight and level number 4 (2 minutes)
10. 360 deg. std. rate climbing left turn
11. Straight and level number 5 (2 minutes)
12. 360 deg. std. rate descending right turn
13. Descend 1000 feet at 500 feet per minute
14. Straight and level number 6 (2 minutes)
15. Instrument landing system (ILS) approach

After completing the resting EEG and the resting P300, the aviator began the series of maneuvers in the standardized flight profile. Once the subject had begun a specific maneuver, the ongoing EEG recording was marked so the data could later be differentiated into different maneuvers (the EEG data collected during maneuvers will be presented in a later report). When a subject completed the maneuver, the EEG recording was marked again to indicate the termination of that maneuver. This process was repeated until all maneuvers were performed, with the exception of the last one (the ILS approach).

In preparation for the ILS, while flying straight-and-level to intercept the localizer beacon, each subject completed another auditory P300. This second P300 was procedurally identical to the resting P300 recorded at the beginning of the flight; however, during the second P300, the subject remained in control of the aircraft. Following this, the subject performed the final maneuver in the flight profile (the ILS approach). No data (EEG or P300) were collected during this last maneuver because of the requirement for subjects to actively communicate with air traffic control and the safety pilot at frequent intervals. Upon completing the ILS approach, the subject relinquished control of the aircraft to the safety pilot who then executed a missed approach at Cairns AAF and returned to the helipad at the Laboratory.

#### In-flight testing for nonpilots

The flight test for nonaviators (conducted separately from those for the aviators) was similar to the one outlined above. However, the nonaviators were seated in the rear of the aircraft where they completed the resting EEGs and the P300s. In addition, their EEGs were monitored during the execution of the flight maneuvers presented in table 1 (these EEG data will be presented in a later report). The USAARL safety pilot and another rated aviator were at the controls during these flights, but no data were collected from either pilot.

#### Data analysis

Each subject tested in this investigation had his/her evoked responses and EEGs recorded under similar conditions on the ground and in the UH-1 so that differences between brain activity recorded in a traditional laboratory setting and brain activity recorded in a helicopter (and then telemetered to the laboratory) could be examined. In addition, each subject had his/her EEG recorded during the performance of in-flight maneuvers so that potential differences in EEG activity as a function of workload could be explored; however, these data will not be presented in this report. P300 data also were recorded under resting conditions in the laboratory, resting conditions in the aircraft, and in the pilots, working conditions in the aircraft (for the nonpilots, there was a second resting P300 in flight) for the purpose of evaluating whether or not it was possible to collect scorable evoked potentials in a helicopter environment. Also, the P300s were collected twice in the aircraft for the purpose of exploring the potential for using this type of data to differentiate workload levels. Thus, each subject's data were subdivided into 2 segments of eyes-open resting EEG (in-flight versus laboratory), 2 segments of eyes-closed resting EEG (in-flight versus laboratory), 14 segments of eyes-open working EEG (one during each in-flight maneuver), and 3 segments of auditory P300s (laboratory resting, in-flight resting, and in-flight-with-pilots working).

To compare the standard laboratory versus in-flight telemetered EEG data, each subject's EEG record was first examined to extract and analyze a minimum of 4 relatively artifact free 2.5-second epochs per condition or maneuver (eyes-open, eyes-closed, maneuvers 1-14). Fast Fourier Transforms (FFTs) were conducted on all 21 active EEG channels for each epoch within

each condition, and the results (4 sets of FFTs--one per epoch) were averaged for each. This approach yielded information about the power distribution of EEG activity at each electrode during each condition for both laboratory and in-flight data. Once the FFTs were complete, the results were transferred to computer for statistical analyses, and the data collected in the laboratory were compared to the data collected in the aircraft.

To compare the standard resting versus the in-flight-resting and in-flight-pilot-working evoked response data, each subject's P300 data first were examined by scoring the latencies and amplitudes (scored from baseline) of the P300 component recorded from Cz and Pz. These scores then were entered into a computerized database for analyses. Data recorded in the laboratory were compared to data recorded in the aircraft at both times (resting and during the ILS). Generally, the collection of these three segments of data allowed a determination of the feasibility of acquiring valid evoked response data from personnel flying in a helicopter. When subdivided into nonpilot and pilot groups, these sets of evoked response data allowed a preliminary examination of whether in-flight evoked response could be used as an index of attentional demands during the performance of flight tasks.

## Results

### Laboratory versus in-flight spontaneous EEG activity of pilots and nonpilots

A series of 3-way, mixed-factorial analyses of variance (ANOVA) was used to determine the effects of subject type (pilot versus nonpilot), condition (laboratory versus in-flight), and eyes (eyes open versus eyes closed) on spontaneous EEG activity. Data from the delta, theta, alpha, and beta bands were examined separately for electrodes C3, C4, Cz, P3, P4, Pz, O1, O2, and Oz. Although with this type of analysis a number of outcomes were possible, the one of primary concern was whether or not there was an interaction between testing condition and eye closure. The reason was that such an interaction would suggest that the typical relationship between eyes-open and eyes-closed EEG activity was somehow distorted as a function of whether testing occurred on the ground or in the air. Main effects (in the absence of higher-order interactions) are of less concern because ultimately the EEGs collected in flight will be used only to compare the EEG of a well-rested, adequately-functioning aviator in flight to his/her own EEG under conditions of stress, fatigue, and performance degradation.

#### Delta

Analysis of delta (1.5-3.0 Hz) activity indicated a single 3-way interaction in the data recorded from Pz ( $F(1,18)=7.38$ ,  $p=.0142$ ). This was due to a condition-by-eyes interaction within the nonpilots but not in the pilots ( $p<.05$ ). In the nonpilots, eyes-open delta was less than eyes-closed delta in flight, but not in the laboratory, whereas in the pilots, there were no differences in either situation (although it appeared there was less delta under eyes open than eyes closed in the laboratory, but not in the aircraft). This 3-way interaction is shown in figure 5. There was a

single 2-way interaction (condition-by-eyes) recorded from Cz ( $F(1,18)=5.08$ ,  $p=.0369$ ). This was due to greater delta activity under eyes closed versus eyes open in the aircraft while there were no differences in the laboratory. There were 3 condition main effects indicative of overall increases in the amount of delta activity recorded in flight versus in the laboratory. More delta activity was recorded in the helicopter at C3 ( $F(1,18)=6.48$ ,  $p=.0202$ ), C4 ( $F(1,18)=9.11$ ,  $p=.0074$ ), and Cz ( $F(1,18)=6.22$ ,  $p=.0226$ ). The amount of delta recorded from several electrode locations under eyes open and eyes closed in the helicopter and in the laboratory is depicted in figure 6.

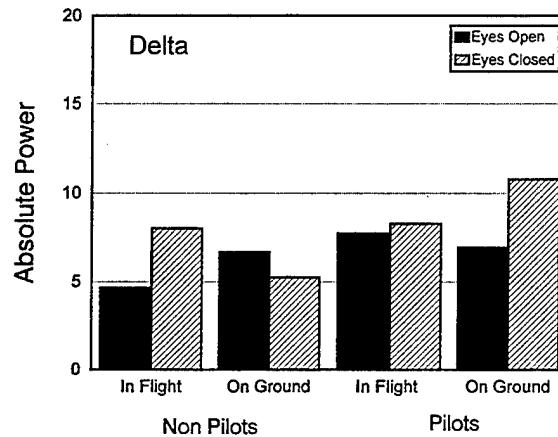


Figure 5. The effects of subject type, testing condition, and eye closure on delta activity recorded from Pz.

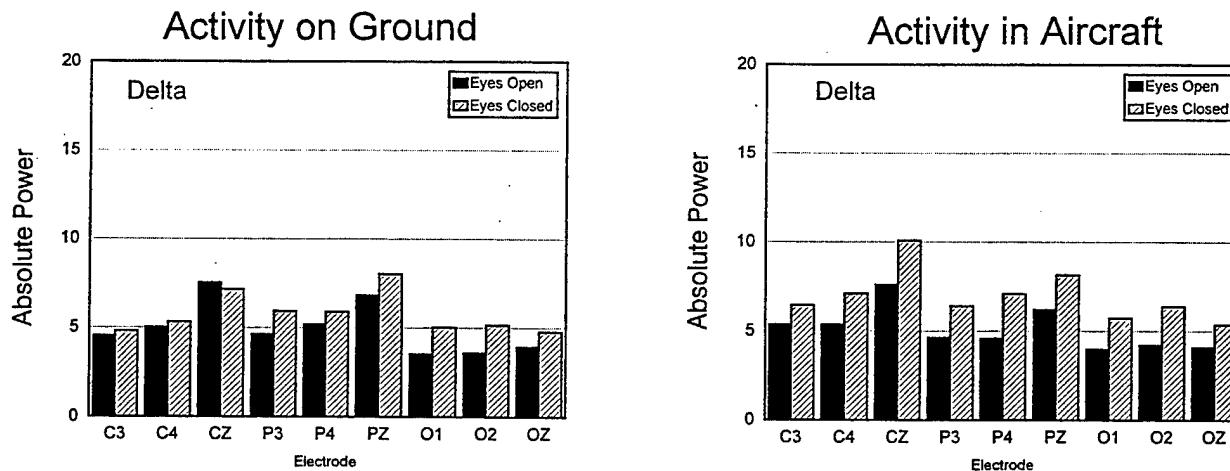


Figure 6. The effects of testing condition and eye closure on delta activity recorded from several electrodes.

### Theta

Analysis of theta (3.0-8.0 Hz) activity revealed no 3-way interactions, but there were 2-way interactions between condition and eyes at C3 ( $F(1,18)=5.29$ ,  $p=.0336$ ) and P3 ( $F(1,18)=8.17$ ,  $p=.0104$ ). Subsequent analyses showed that although there was more theta under eyes closed than under eyes open in both conditions (in-flight and laboratory), the differences were larger in the helicopter than on the ground. There were main effects on the eyes factor at every electrode site: C3 ( $F(1,18)=12.55$ ,  $p=.0023$ ), C4 ( $F(1,18)=7.31$ ,  $p=.0145$ ), Cz ( $F(1,18)=15.76$ ,  $p=.0009$ ), P3 ( $F(1,18)=10.03$ ,  $p=.0053$ ), P4 ( $F(1,18)=15.57$ ,  $p=.0009$ ), Pz ( $F(1,18)=11.33$ ,  $p=.0034$ ), O1 ( $F(1,18)=8.05$ ,  $p=.0109$ ), O2 ( $F(1,18)=8.10$ ,  $p=.0107$ ), and Oz ( $F(1,18)=8.25$ ,  $p=.0101$ ). All of these were attributable to more theta under eyes closed than eyes open. There also were main effects on the condition factor at P3 ( $F(1,18)=10.23$ ,  $p=.0050$ ), P4 ( $F(1,18)=5.74$ ,  $p=.0277$ ), O1 ( $F(1,18)=15.48$ ,  $p=.0010$ ), O2 ( $F(1,18)=10.26$ ,  $p=.0049$ ), and Oz ( $F(1,18)=9.55$ ,  $p=.0063$ ). In every case, the amount of recorded theta was greater in the aircraft than in the laboratory. The theta activity recorded from several electrodes under eyes open and eyes closed in the laboratory and in the aircraft is presented in figure 7.

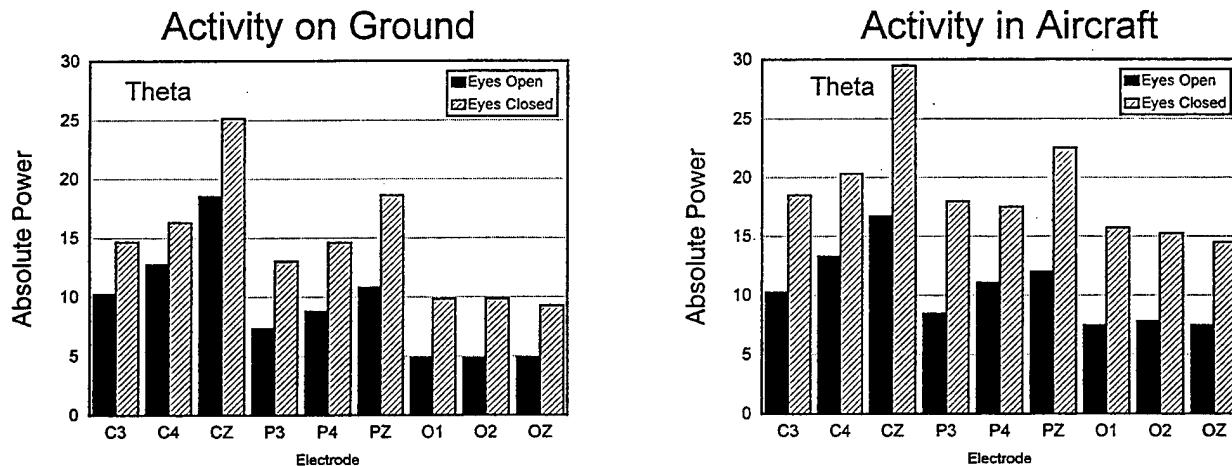


Figure 7. The effects of testing condition and eye closure on theta activity recorded from several electrodes.

### Alpha

The analyses of alpha (8.0-13.0 Hz) activity indicated interactions between subject type (pilots versus nonpilots) and condition, and main effects on the eyes factor and the condition factor. There were subject-type-by-condition interactions at C3 ( $F(1,18)=7.63$ ,  $p=.0128$ ), C4 ( $F(1,18)=5.58$ ,  $p=.0296$ ), Cz ( $F(1,18)=7.52$ ,  $p=.0134$ ), P3 ( $F(1,18)=8.50$ ,  $p=.0092$ ), and P4 ( $F(1,18)=5.16$ ,  $p=.0356$ ). Analysis of simple effects indicated this was due to the fact that pilots manifested a difference in the amount of alpha activity generated in the helicopter versus the laboratory ( $p<.05$ ) whereas the nonpilots did not. Visual inspection of the means for pilots indicated significantly more alpha activity in the helicopter than on the ground (see figure 8).

The eyes main effects were because of more alpha activity under eyes closed than eyes open at every electrode location: C3 ( $F(1,18)=32.87$ ,  $p<.0001$ ), C4 ( $F(1,18)=29.52$ ,  $p<.0001$ ), Cz ( $F(1,18)=32.93$ ,  $p<.0001$ ), P3 ( $F(1,18)=24.07$ ,  $p<.0001$ ), P4 ( $F(1,18)=23.13$ ,  $p=.0001$ ), Pz ( $F(1,18)=23.31$ ,  $p=.0001$ ), O1 ( $F(1,18)=19.10$ ,  $p=.0004$ ), O2 ( $F(1,18)=19.00$ ,  $p=.0004$ ), and Oz ( $F(1,18)=15.55$ ,  $p=.0010$ ). The condition main effects were due to the presence of more alpha in flight than in the standard laboratory environment at C3 ( $F(1,18)=10.88$ ,  $p=.0040$ ), C4 ( $F(1,18)=8.99$ ,  $p=.0077$ ), Cz ( $F(1,18)=12.60$ ,  $p=.0023$ ), P3 ( $F(1,18)=6.05$ ,  $p=.0242$ ), P4 ( $F(1,18)=10.31$ ,  $p=.0048$ ), Pz ( $F(1,18)=11.05$ ,  $p=.0038$ ), O1 ( $F(1,18)=11.12$ ,  $p=.0037$ ), O2 ( $F(1,18)=7.58$ ,  $p=.0131$ ), and Oz ( $F(1,18)=7.26$ ,  $p=.0148$ ). The amount of alpha activity recorded from several electrodes in the aircraft and in the laboratory (collapsed across the pilots and nonpilots) is shown in figure 9.

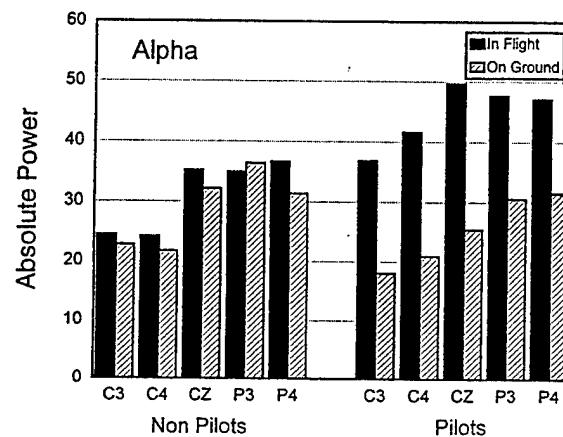


Figure 8. The effects of subject type and testing condition on EEG activity recorded from several electrode locations.

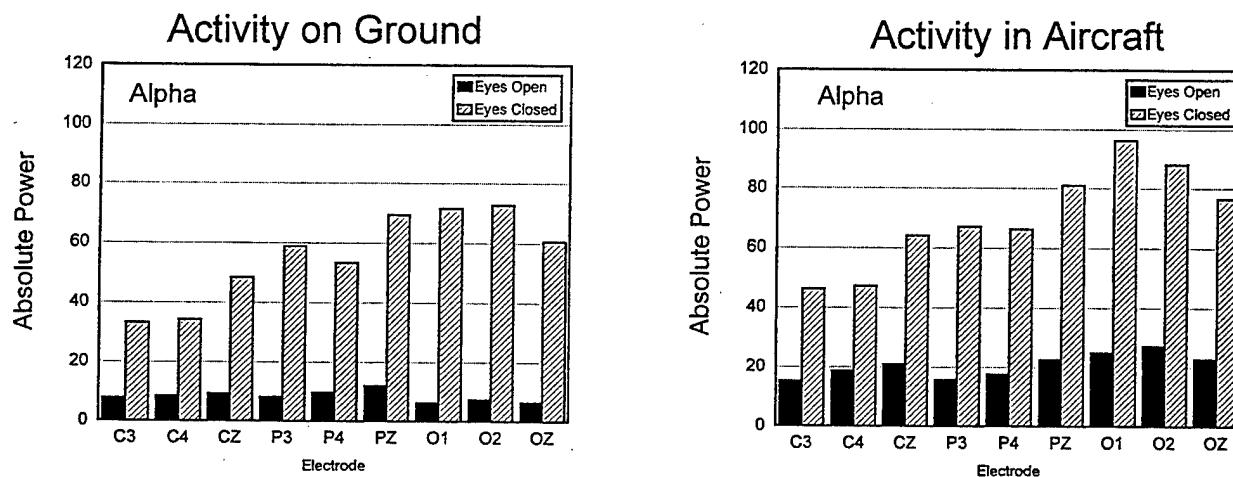


Figure 9. The effects of testing condition and eye closure on alpha activity recorded from several electrodes.

## Beta

The analysis of beta (13-20 Hz) activity indicated 2-way interactions between subject type and condition at C3 ( $F(1,18)=5.79$ ,  $p=.0271$ ), C4 ( $F(1,18)=6.49$ ,  $p=.0202$ ), Cz ( $F(1,18)=4.82$ ,  $p=.0415$ ), P3 ( $F(1,18)=8.05$ ,  $p=.0109$ ), P4 ( $F(1,18)=7.26$ ,  $p=.0148$ ), Pz ( $F(1,18)=12.92$ ,  $p=.0021$ ), O1 ( $F(1,18)=6.35$ ,  $p=.0214$ ), O2 ( $F(1,18)=6.86$ ,  $p=.0174$ ), and Oz ( $F(1,18)=8.66$ ,  $p=.0087$ ). Analysis of simple effects showed there were differences in the amount of beta recorded under the two testing conditions within the pilots ( $p<.05$ ), but not in the nonpilots. The mean beta activity of the pilots at each electrode location was substantially larger in the helicopter than in the laboratory, whereas the mean activity of the nonpilots was virtually identical in both settings (see figure 10). There were also group main effects in the beta recorded from C3 ( $F(1,18)=9.31$ ,  $p=.0069$ ), C4 ( $F(1,18)=8.80$ ,  $p=.0083$ ), Cz ( $F(1,18)=7.41$ ,  $p=.0140$ ), P3 ( $F(1,18)=6.35$ ,  $p=.0214$ ), P4 ( $F(1,18)=5.19$ ,  $p=.0351$ ), and Pz ( $F(1,18)=7.08$ ,  $p=.0159$ ), all of which were due to the presence of more beta activity in the pilots than in the nonpilots. There were main effects on both the condition and eyes factor as well. Condition main effects were observed at C3 ( $F(1,18)=7.93$ ,  $p=.0115$ ), C4 ( $F(1,18)=12.19$ ,  $p=.0026$ ), Cz ( $F(1,18)=8.26$ ,  $p=.0101$ ), P3 ( $F(1,18)=7.73$ ,  $p=.0124$ ), P4 ( $F(1,18)=14.66$ ,  $p=.0012$ ), Pz ( $F(1,18)=13.61$ ,  $p=.0017$ ), O1 ( $F(1,18)=11.74$ ,  $p=.0030$ ), O2 ( $F(1,18)=13.28$ ,  $p=.0019$ ), and Oz ( $F(1,18)=12.04$ ,  $p=.0027$ ). In each case, more beta activity was recorded from the helicopter environment than in the laboratory. Eyes main effects were found at C3 ( $F(1,18)=7.35$ ,  $p=.0143$ ), C4 ( $F(1,18)=7.43$ ,  $p=.0139$ ), Cz ( $F(1,18)=6.51$ ,  $p=.0201$ ), P3 ( $F(1,18)=18.88$ ,  $p=.0004$ ), P4 ( $F(1,18)=8.10$ ,  $p=.0107$ ), Pz ( $F(1,18)=10.39$ ,  $p=.0047$ ), and O1 ( $F(1,18)=5.03$ ,  $p=.0378$ ), and all of these were attributable to greater amounts of beta under eyes closed than eyes open. The amount of beta activity recorded under eyes open and eyes closed in the aircraft and in the laboratory is shown in figure 11.

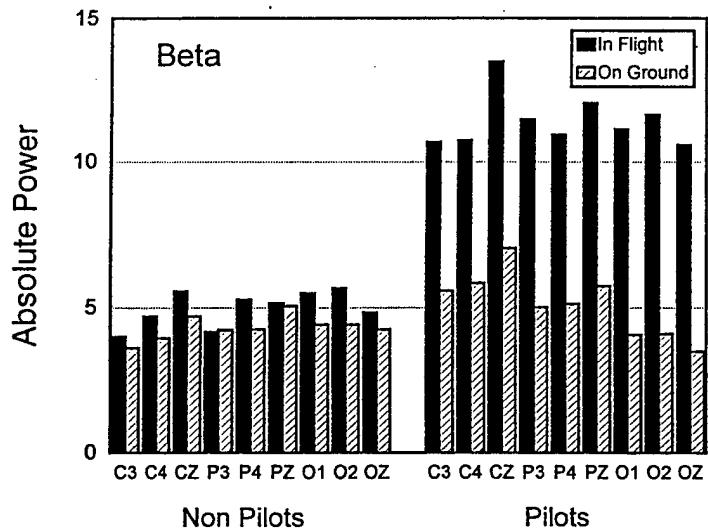


Figure 10. The effects of subject type and testing condition on the amount of beta activity recorded from several electrode locations.

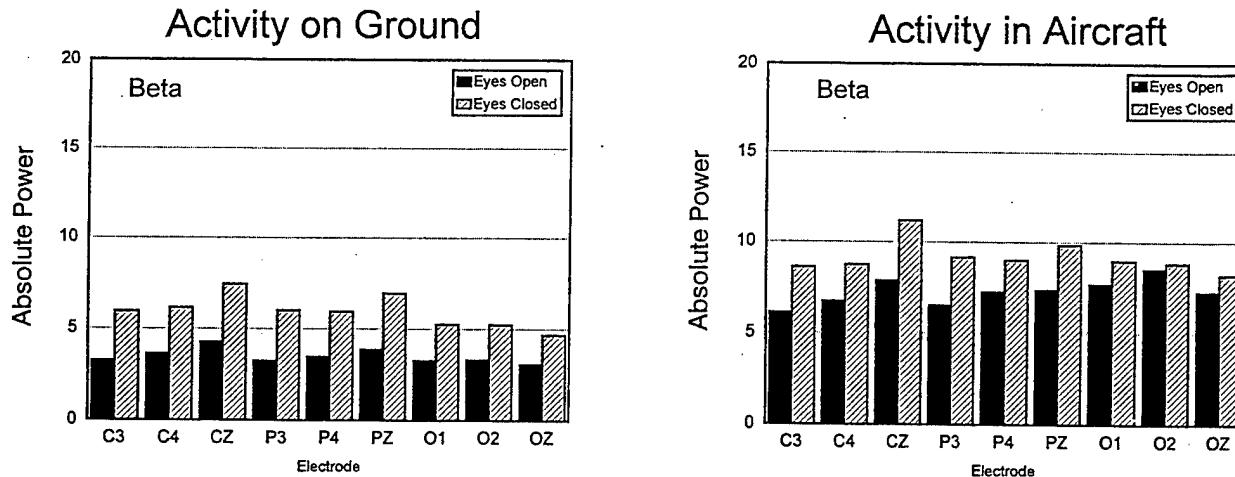


Figure 11. The effects of testing condition and eye closure on beta activity recorded from several electrodes.

#### Laboratory versus in-flight spontaneous EEG activity of pilots only

Since this was only the second study conducted to determine the feasibility of collecting EEG data from helicopter pilots in flight, a subset of analyses was performed on the data from only the pilots. This permitted a direct comparison between the results of this investigation (with 10 pilots) and the results of an earlier investigation (with 8 pilots). Such a comparison seemed warranted since there is some subjectivity in the selection of EEG epochs for analysis, and different technicians scored the records used in the two investigations. Although there were slight differences in the scoring bands that were used in the two studies, it was expected that inconsistencies would be minimal. At worst, it was hoped the discrepancy would result in an overall difference in the number of main effects, but no differences in the number of interactions (since the presence of condition-by-eyes interactions would have indicated that the expected relationship between eyes open and eyes closed EEG activity was differentially affected by the testing environment).

A series of 2-way ANOVAs was conducted on the data from the pilots in which the effects of condition and eyes, and the interactions between condition and eyes were examined for the same electrode locations (Fz, Cz, Pz, P3, P4, O1, and O2) used in Caldwell et al. (1994). For the sake of brevity, the findings are presented in tabular form (see table 2) with the left side of each column showing significant results (indicated by a plus sign) from the first study, and the right side of each column showing significant results from the present study.

**Table 2.**  
Comparisons between the results of the first EEG telemetry study and the present study.

Effect	Delta		Theta		Alpha		Beta	
	Study 1	Study 2						
<b>Condition</b>								
Fz	+	+	-	-	+	+	-	-
Cz	-	-	+	-	+	+	+	+
Pz	-	-	+	-	-	+	-	+
P3	-	-	-	+	-	+	-	+
P4	-	-	+	-	-	+	-	+
O1	-	-	+	+	+	+	+	+
O2	-	+	+	+	-	+	-	+
<b>Eyes</b>								
Fz	-	-	-	-	+	+	+	-
Cz	-	-	-	+	+	+	+	-
Pz	-	-	-	+	+	+	+	+
P3	-	-	-	+	+	+	+	-
P4	-	-	-	+	+	+	+	-
O1	-	-	-	+	+	+	+	-
O2	-	-	-	+	+	+	+	-
<b>Cond-by-Eyes</b>								
Fz	-	-	-	-	-	-	-	-
Cz	-	-	-	-	-	-	-	-
Pz	-	-	-	-	-	-	-	-
P3	-	-	-	-	-	-	-	-
P4	-	-	-	-	-	-	-	-
O1	-	-	-	-	-	-	-	-
O2	-	-	-	-	-	-	-	-

#### Laboratory versus in-flight auditory P300s

The average P300 data for each subject were scored from electrode locations Cz and Pz in terms of both latency (in milliseconds) and amplitude (in microvolts). A 2-way ANOVA was conducted on each set of measures to determine the impact of subject type (pilot versus nonpilot) and testing condition (laboratory-resting, in-flight-resting, and in-flight-ILS) on the P300 component of the evoked potential. Analysis of the latency data indicated neither main effects nor interactions. However, analysis of the amplitude data revealed main effects attributable to differences between the subject groups at Cz ( $F(1,18)=17.44$ ,  $p=.0006$ ) and Pz ( $F(1,18)=14.60$ ,  $p=.0013$ ), and among the test conditions at Cz ( $F(2,36)=3.26$ ,  $p=.0501$ ). Mean amplitudes of the

pilots' P300s were much larger than the nonpilots'. The condition effect was because P300 amplitudes were greater in the laboratory-resting condition than in the in-flight-resting condition ( $p < .05$ ); however, none of the other comparisons were significant (although the laboratory-resting versus the in-flight-ILS comparison was marginally significant at  $p = .08$ ). The mean latencies and amplitudes for the pilots and nonpilots are depicted in figures 12 and 13.

The P300s were further examined to evaluate any tendencies suggesting these data could provide an indication of workload-induced changes in pilots in flight. Since the nonpilots were simply resting in the rear of the aircraft throughout all of the in-flight testing, their data were excluded from this analysis. Instead, only the pilots' P300s were evaluated across the three testing conditions (laboratory resting, in-flight resting, and on-the-controls flying prior to the ILS). There were no significant effects on the P300 latencies recorded from either Cz or Pz, and as noted above, there was only a small indication of any tendency toward latency changes across test conditions. There also were no significant effects on P300 amplitudes, but there was a tendency ( $p = .09$  for Cz and  $p = .19$  for Pz) for the P300s recorded in the laboratory to have been smaller than the ones recorded in the aircraft. A similar tendency was not observed in the nonpilots.

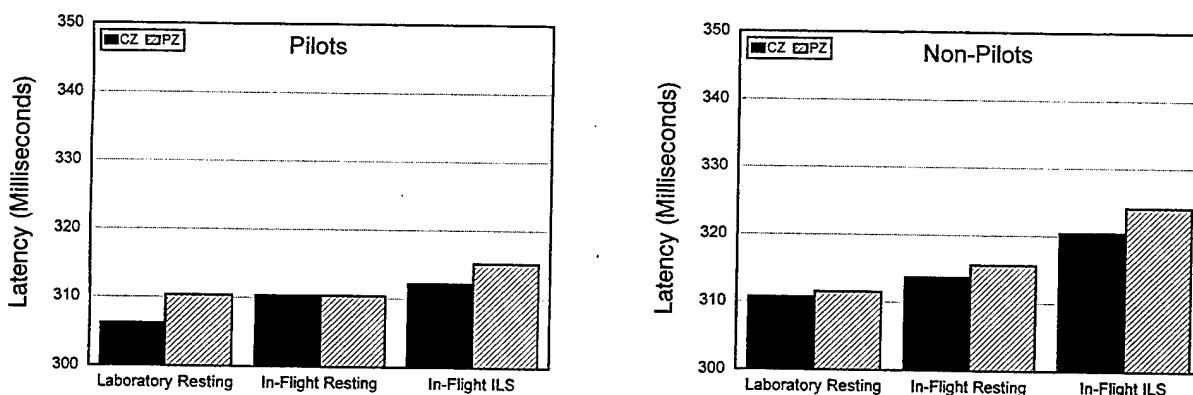


Figure 12. The effects of subject type and testing condition on P300 latencies.

### Discussion

The results from this study, in which 20 subjects (10 aviators in the pilot's seat of the aircraft and 10 nonaviators seated in the rear of the aircraft) were tested, indicated that both spontaneous EEG activity and cortical evoked responses can be recorded adequately in a utility helicopter. This is despite the fact that temperature extremes, turbulence, noise, and vibration absent from the laboratory, is a problem in the in-flight environment. Overall, there were few meaningful differences in laboratory-based recordings and in-flight recordings.

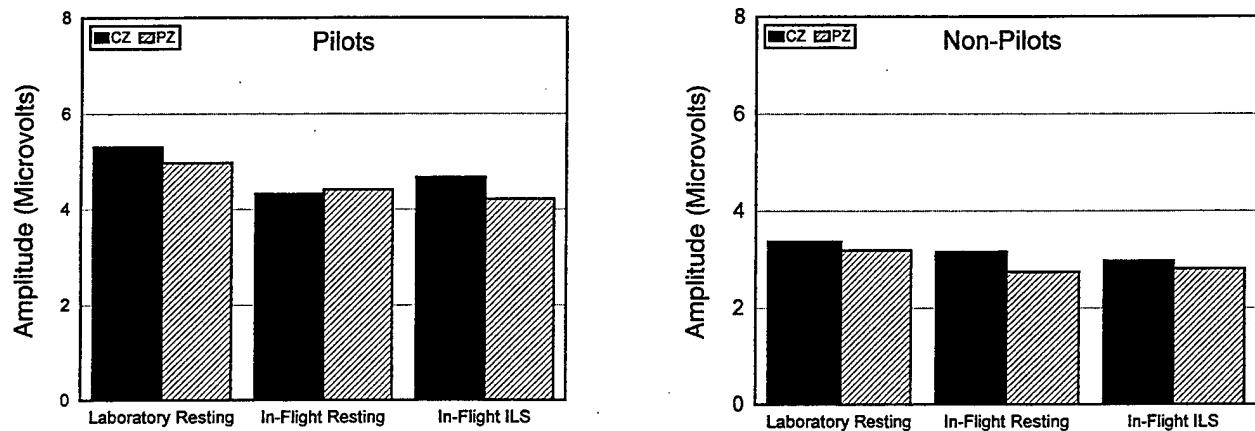


Figure 13. The effects of subject type and testing condition on P300 amplitudes.

#### Spontaneous EEG activity

The analysis of eyes-open and eyes-closed EEG data indicated an overall increase in the amounts of delta, theta, alpha, and beta activity recorded in flight relative to what was recorded in the standard laboratory environment. This fairly robust effect was probably due at least partially to vibration artifact from the main rotor blades which produces a fundamental frequency of 10.8 Hz. Also, the increase in beta activity may have been associated with an increase in muscle tension required to compensate for vibration effects in the helicopter. However, since neither effect obscured the expected EEG changes associated with eye closure (eyes-open versus eyes-closed activity), they are not cause for significant concern.

In general, the EEG findings from this study were in agreement with those of an earlier study (Caldwell et al., 1994) in which only eight pilots were tested. Specifically, both investigations strongly support the feasibility of monitoring EEG activity from personnel flying in a helicopter environment. However, there were differences here that did not appear in the earlier investigation.

One difference was that more main effects attributable to the testing environment (laboratory versus helicopter) were significant in the present study than in Caldwell et al. (1994). In the present study (where the data from 9 electrodes were examined), there were a total of 26 significant main effects due to increased delta, theta, alpha, and beta activity recorded in the aircraft. In the earlier telemetry study (in which the data from 7 electrodes were examined), there were only 11 similar effects. Part of this difference was no doubt due to the fact that more electrodes were evaluated in the present study than in the earlier study (thus offering more opportunities to find significant differences). The remainder of the discrepancies are probably

attributable to power differences across the two investigations. More subjects were tested in this study than in the earlier one, and because of the consequent increase in design power, there was an increase in the number of significant findings. The plausibility of this explanation is supported by visual inspection of the mean delta, theta, alpha, and beta activity recorded in the Caldwell et al. (1994) study. Although the differences were not always statistically significant, there was a clear tendency toward an increase from the laboratory to the aircraft in the various types of EEG activity. If the earlier study had involved more participants, the results of the two investigations likely would have been more similar.

Another difference between the two studies was in the effects of eye closure on EEG activity. Although there were only slight discrepancies in terms of the effects of eyes-open/eyes-closed manipulations on delta, alpha, and beta activity, many more theta main effects were found in the present study than in the earlier one. In fact, there was a substantial increase in theta activity recorded from eyes open to eyes closed at every electrode in this study, whereas this increase in theta (although suggested from a visual inspection of the means) was not significant in the first investigation. Perhaps the increased design power from Caldwell et al. (1994) to the present was once again responsible for this difference.

In both of these cases (testing-environment differences and eyes-open/eyes-closed differences), the fact that there were some overall changes in the amount of EEG activity recorded under the different conditions is not thought to be a serious cause for concern. Even if these effects are not simply a result of differences in design factors, it is possible that the use of different subjects or different research technicians in the two studies could have accounted for the discrepancies. Also, it should be noted that the definitions of the EEG bands were changed slightly from one study to the other, and this could have produced some changes in the results. In the first study, the bands were defined as delta (1.5-3.0 Hz), theta (3.0-7.5 Hz), alpha (7.5-13.0 Hz), and beta (13.0-20.0 Hz); whereas, in the present study, the bands were defined as delta (1.5-3.0 Hz), theta (3.0-8.0 Hz), alpha (8.0-13.0 Hz), and beta (13.0-20.0 Hz). Perhaps this redefinition could have caused some of the discrepancies. However, whether the main effects were attributable to design factors or procedural influences, the observed differences were not qualitatively different to the extent that they raise serious cause for concern. In fact, it was often the case that where there were statistically significant effects in the present study as opposed to the earlier one, an examination of the means from the earlier study showed at least a generally consistent, non-significant trend in the data. There were no reversals of effects (or reversals in tendencies toward specific effects) in any respect (i.e., there was no evidence that in one study eyes-open theta was greater than eyes-closed theta whereas in the other study the opposite was true). Thus, the observed discrepancies generally were attributable to the *magnitude of effects* or the *sensitivity of the design for detecting effects* rather than more problematic changes in the overall pattern of results.

One place where differences were noted that could have been more problematic was with regard to interactions between the testing environment and the eyes-open/eyes-closed conditions. In Caldwell et al. (1994), not a single interaction of this type was found, whereas in the present

study, there was some evidence of this interaction within the delta band (at Pz and Cz) and theta band (at C3 and P3). In all four cases, the increases in activity from eyes open to eyes closed were significantly accentuated in the aircraft relative to what was found under standard laboratory conditions. This type of effect suggested an unwanted distortion of the relationship between eyes open and eyes closed EEG activity based simply on the testing environment; however, the fact that there were only 4 such interactions out of the 36 that were possible (9 electrodes x 4 EEG activity bands) indicates the finding is more likely an artifact due to the number of statistical tests conducted or the already noted design factors (more electrodes and more subjects) rather than to any real discrepancy between the results of the 2 investigations. Also, it should be noted that even if, based on the present study, it is assumed that the testing environment exerts a real impact on the *amount* of change in EEG activity recorded at these 3 electrodes, the *direction* of the change was not affected. Thus, there was always more activity recorded under eyes-closed than eyes-open regardless of whether testing occurred in the laboratory or the aircraft, but the magnitude of this difference was simply accentuated in flight.

To further substantiate that the most important finding from the earlier telemetry study (e.g. the absence of condition-by-eyes interactions) was supported by the present data, an analysis of the data was performed in which only the pilots were examined (only pilots were tested in the earlier study). The side-by-side comparison (present study versus earlier study) indicated that, while there were some differences between the two studies in the main effects, there were no condition-by-eyes interactions at any electrode location in any activity band. Thus, it appears that in both studies, the expected EEG changes from eyes-open to eyes-closed testing were virtually identical regardless of whether these changes were observed in a helicopter environment or in a standard laboratory environment. This indicates that valid EEG recordings can be made from helicopter pilots in flight.

#### Evoked responses

Whereas the EEG portion of the present study was performed primarily to replicate the findings from an earlier smaller investigation, the collection and analysis of cortical evoked responses was a novel effort. The auditory P300s collected here were done principally to evaluate whether or not the noise and vibration present in the helicopter environment would render standard evoked responses unscorable. Toward this objective, all 21 channels of data were qualitatively compared to data collected in the laboratory, and 2 channels of data were quantitatively compared to evaluate the potential utility of cortical evoked responses as an in-flight measure of pilot status. The result of these comparisons was quite favorable in that few substantial qualitative changes in the P300 waveforms were observable as a function of testing situation (laboratory versus in-flight). In addition, the statistical analysis of the waveforms recorded from Cz and Pz (the scalp locations at which P300s are typically maximal) showed there were no differences from the laboratory to the aircraft in either the latency or the amplitude of the P300 at Pz.

The data from Cz showed that, despite the absence of latency changes, there was a small but significant reduction in the amplitude of the P300 from the laboratory to the aircraft. It is possible this was due to vibration-related artifact which could have reduced the magnitude of the averaged P300 component by increasing the variability in the peak amplitude during sampling. Alternatively, the amplitude difference could have been a product of attentional shifts from the relatively quiet, distraction-free laboratory environment to the more active helicopter setting. It is known that P300 amplitude depends on selective attention to the eliciting stimuli (Pritchard, 1981). Thus, distractions due to in-flight activities may have caused the observed amplitude reductions.

A second reason for collecting auditory P300s in this study was to determine whether or not these data might be useful for monitoring the workload levels of pilots. Unfortunately, the results did not offer substantial indications that this was the case. There were slight tendencies toward longer P300 latencies as pilots progressed from laboratory-resting to in-flight-resting to in-flight-on-the-controls segments of the study, but none of these were significant, and the non-significant tendencies were present in the nonpilots as well. Thus, although valid P300s can be collected from pilots in flight, a decision about the sensitivity of the P300 to workload changes must await further systematic evaluation.

### Conclusions

The results from this investigation supported the earlier findings of Caldwell et al. (1994) by indicating the feasibility of collecting and telemetering spontaneous EEG activity from personnel flying onboard a UH-1 helicopter. In addition, this study provided evidence that the in-flight monitoring of cortical evoked responses (auditory P300s) is feasible as well. Although the EEG recordings from the aircraft contain more movement and other types of artifact than recordings made in a standard laboratory environment, careful epoch selection (for the EEG) and the application of automatic artifact rejection algorithms (for the evoked potentials) can yield reliable and valid final results.

Future analyses will examine the utility of monitoring EEG activity during the conduct of actual flight maneuvers in addition to monitoring EEG during resting conditions (as was done here). In addition, the potential for using real-time EEGs to assess pilot workload levels will be explored.

A follow-on study is needed to determine whether the telemetered EEGs and evoked responses can be useful in assessing the status of stressed personnel. An examination of sleep-deprived pilots could provide information about the relationship between fatigue-related changes in central nervous system activation and impaired performance. This will necessitate that EEG and flight-performance data be collected concurrently from aviators before and after exposure to significant sleep loss. Based on the present findings (regarding the feasibility of telemetering EEGs from pilots) and those of earlier laboratory studies (which suggest an association between

EEG changes and performance decrements in sleepy pilots), it is anticipated there will be a marked relationship between in-flight EEG activity and in-flight performance. However, the magnitude of this relationship and the extent to which it may offer some capability to predict impending operational problems remains to be determined.

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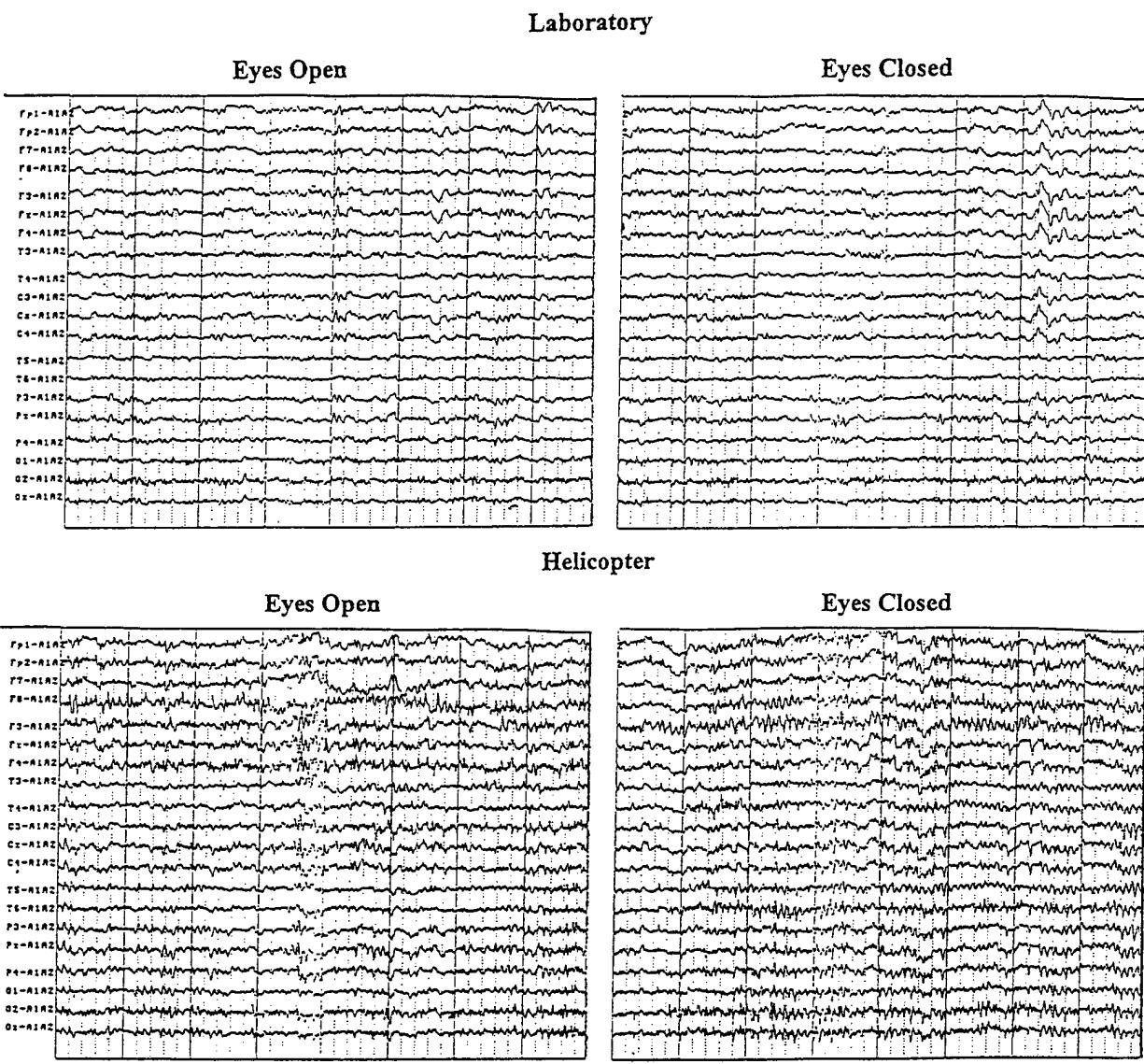
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## Appendix A.

### Part 1. Examples of EEG data collected from each subject.



**Figure A-1.** An 8-second page of EEG data collected from pilot 1 collected under eyes-open and eyes-closed conditions in the helicopter and in the laboratory.

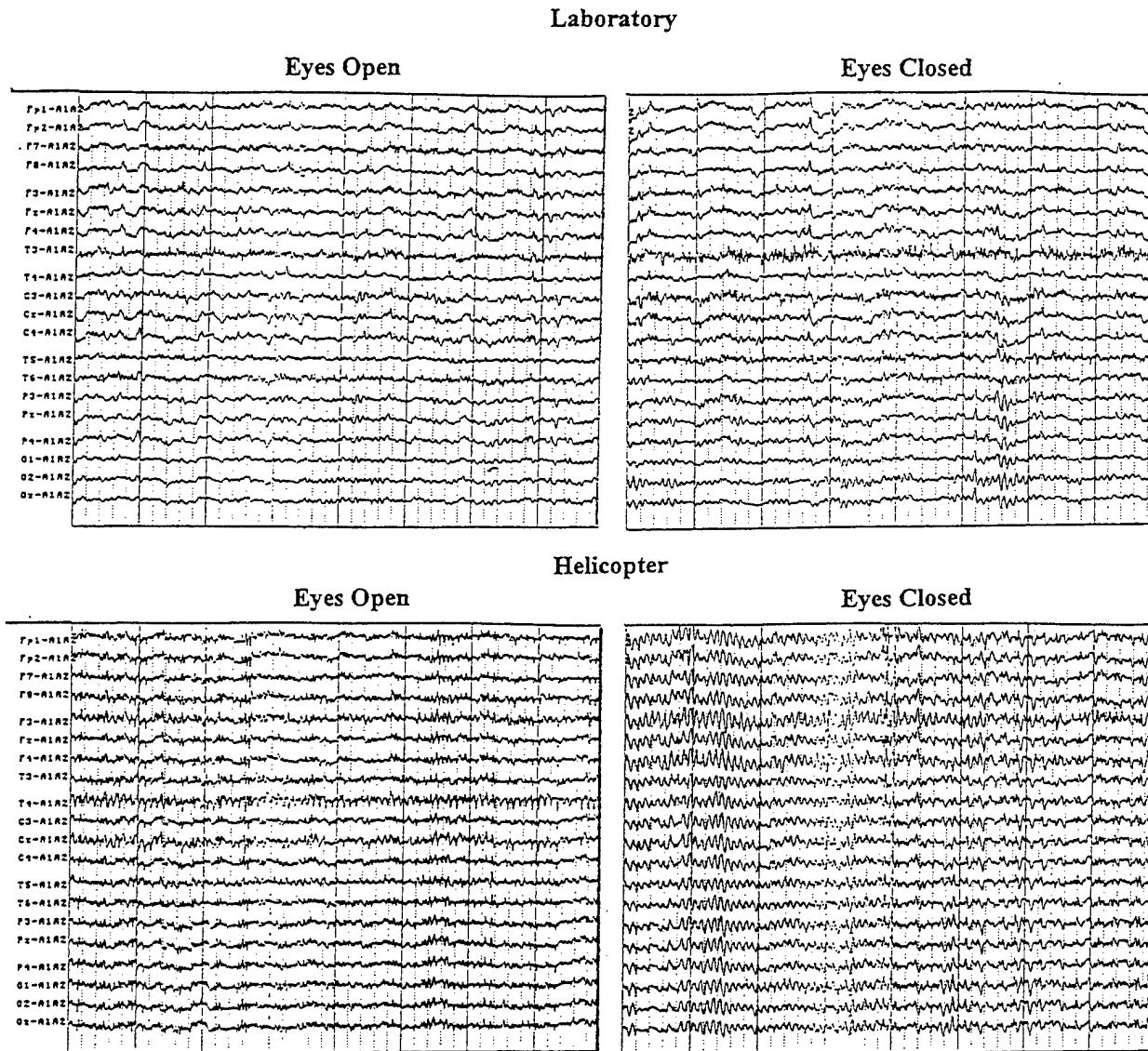


Figure A-2. An 8-second page of EEG data collected from pilot 2 collected under eyes-open and eyes-closed conditions in the helicopter and in the laboratory.

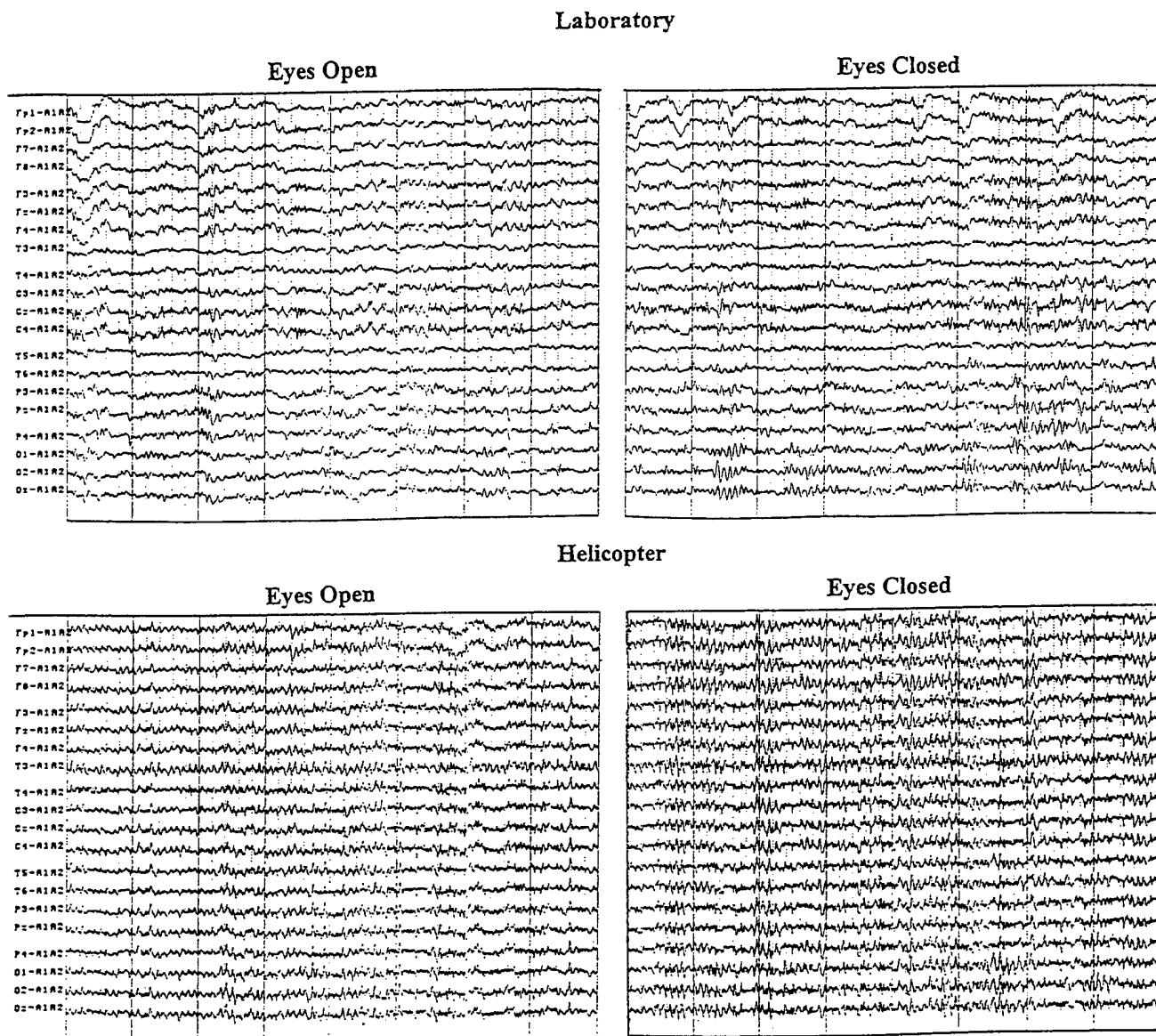


Figure A-3. An 8-second page of EEG data collected from pilot 3 collected under eyes-open and eyes-closed conditions in the helicopter and in the laboratory.

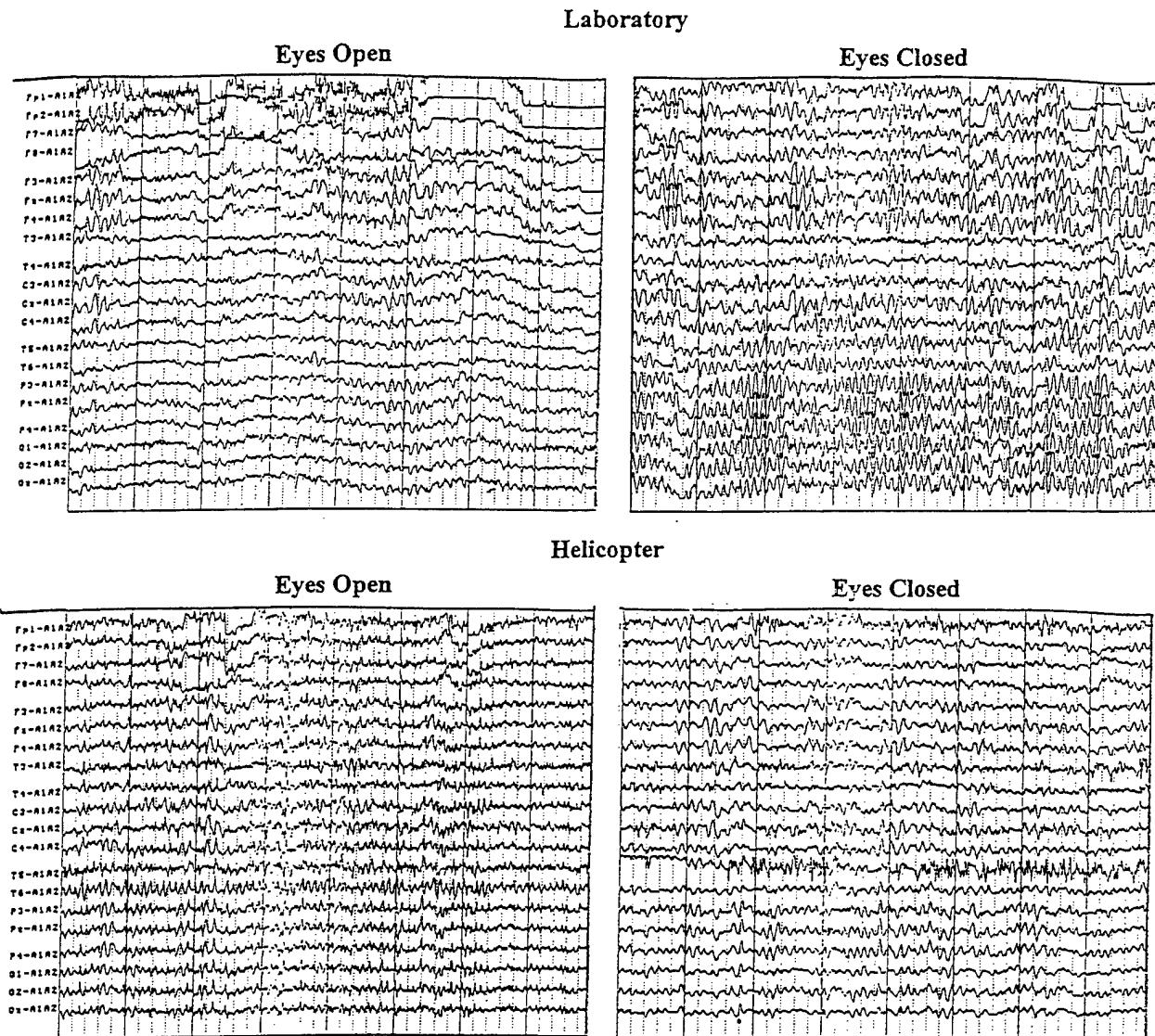


Figure A-4. An 8-second page of EEG data collected from pilot 4 collected under eyes-open and eyes-closed conditions in the helicopter and in the laboratory.

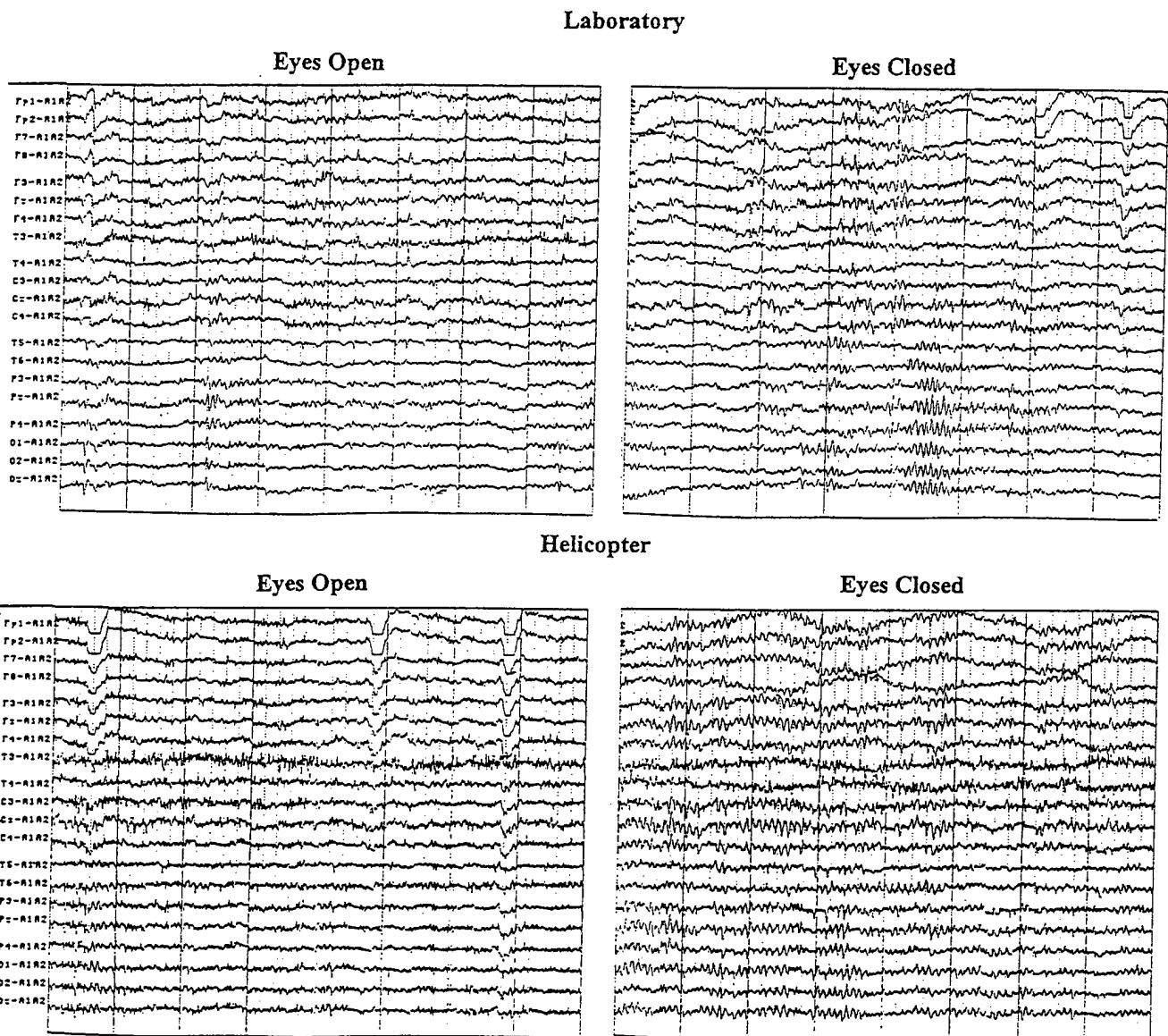


Figure A-5. An 8-second page of EEG data collected from pilot 5 collected under eyes-open and eyes-closed conditions in the helicopter and in the laboratory.

**Laboratory**

Eyes Open

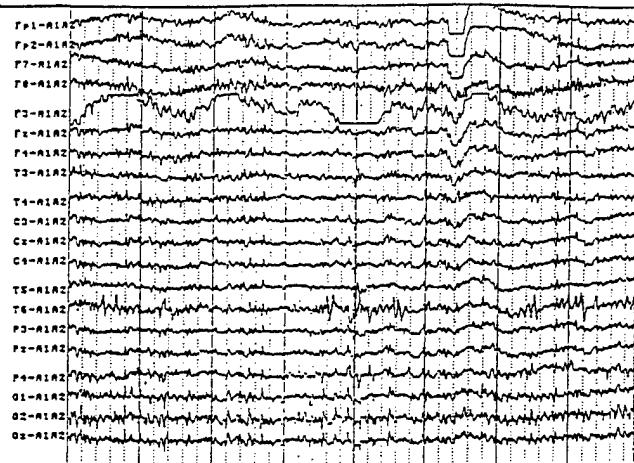


Eyes Closed



**Helicopter**

Eyes Open



Eyes Closed

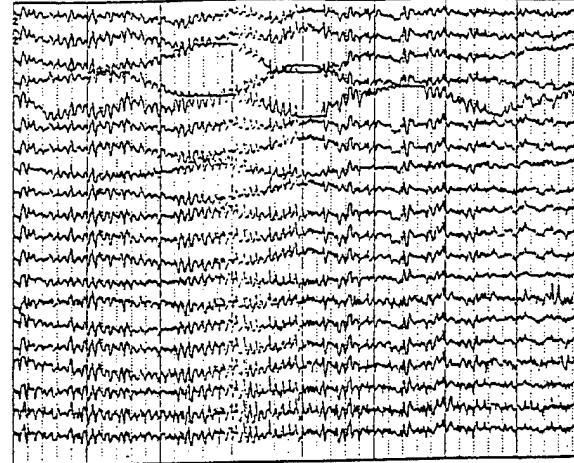


Figure A-6. An 8-second page of EEG data collected from pilot 6 collected under eyes-open and eyes-closed conditions in the helicopter and in the laboratory.

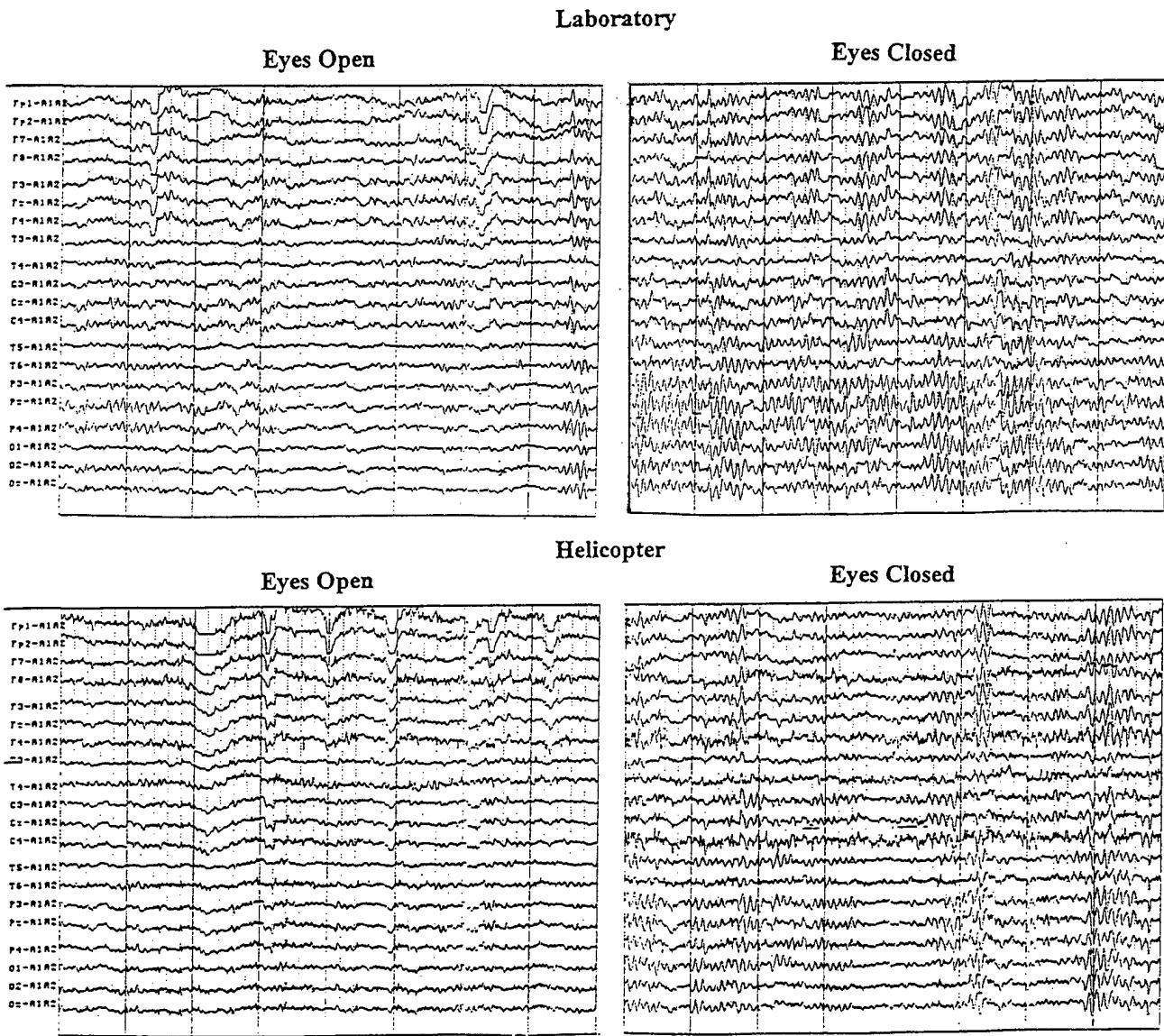


Figure A-7. An 8-second page of EEG data collected from pilot 7 collected under eyes-open and eyes-closed conditions in the helicopter and in the laboratory.

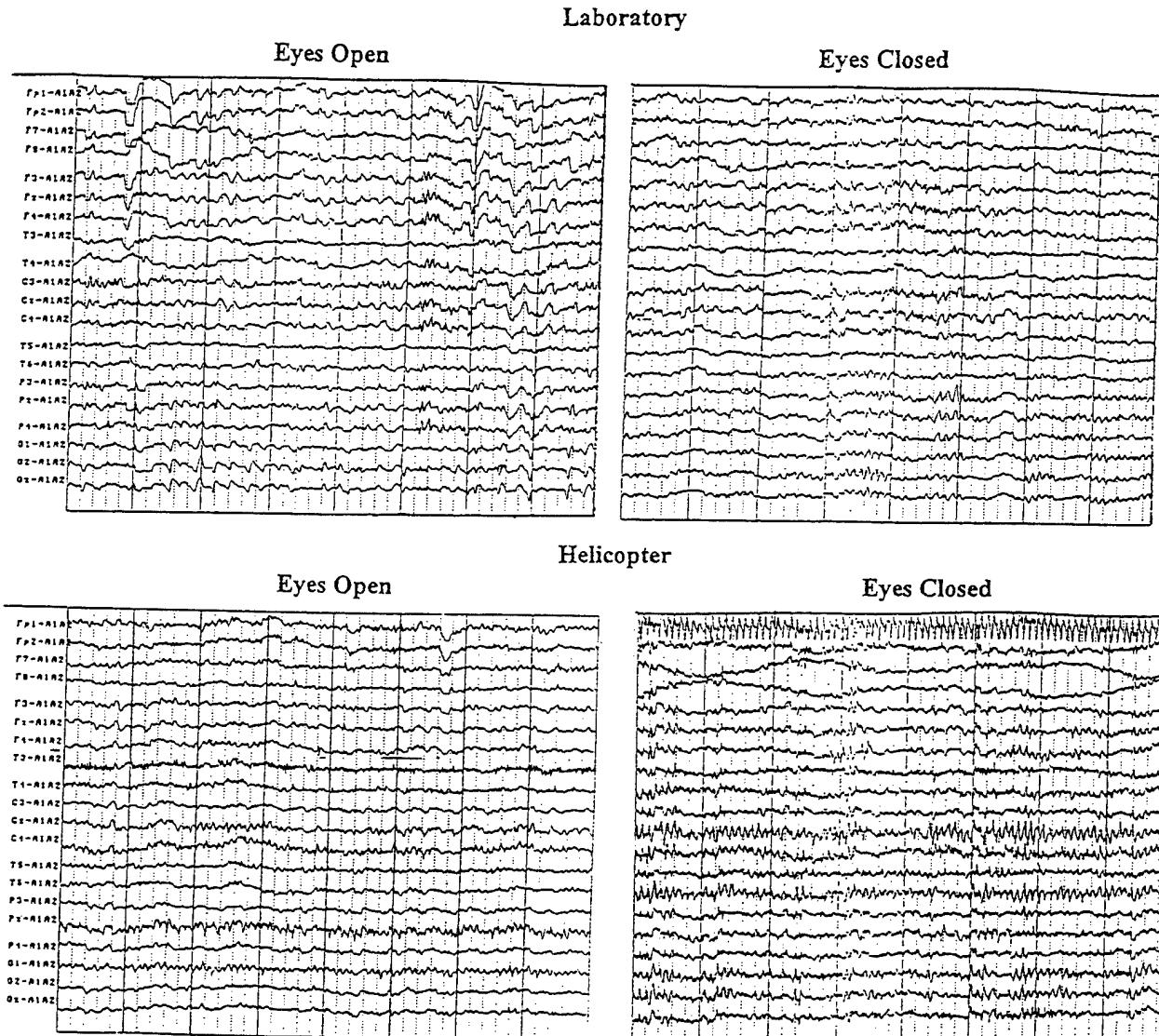


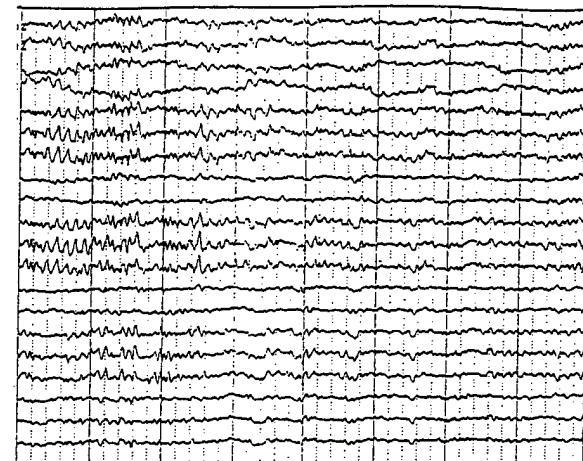
Figure A-8. An 8-second page of EEG data collected from pilot 8 collected under eyes-open and eyes-closed conditions in the helicopter and in the laboratory.

Laboratory

Eyes Open

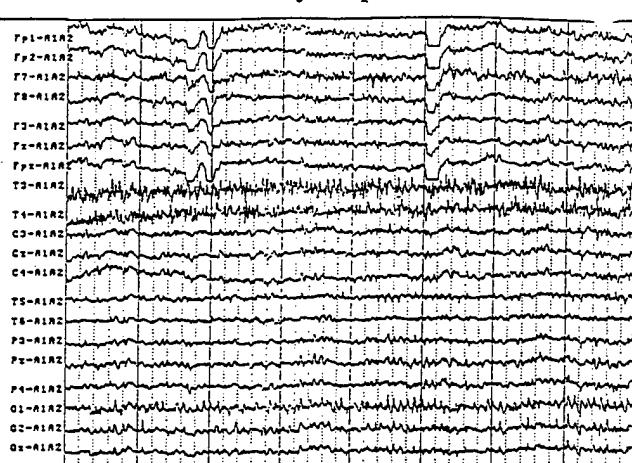


Eyes Closed



Helicopter

Eyes Open



Eyes Closed



Figure A-9. An 8-second page of EEG data collected from pilot 9 collected under eyes-open and eyes-closed conditions in the helicopter and in the laboratory.

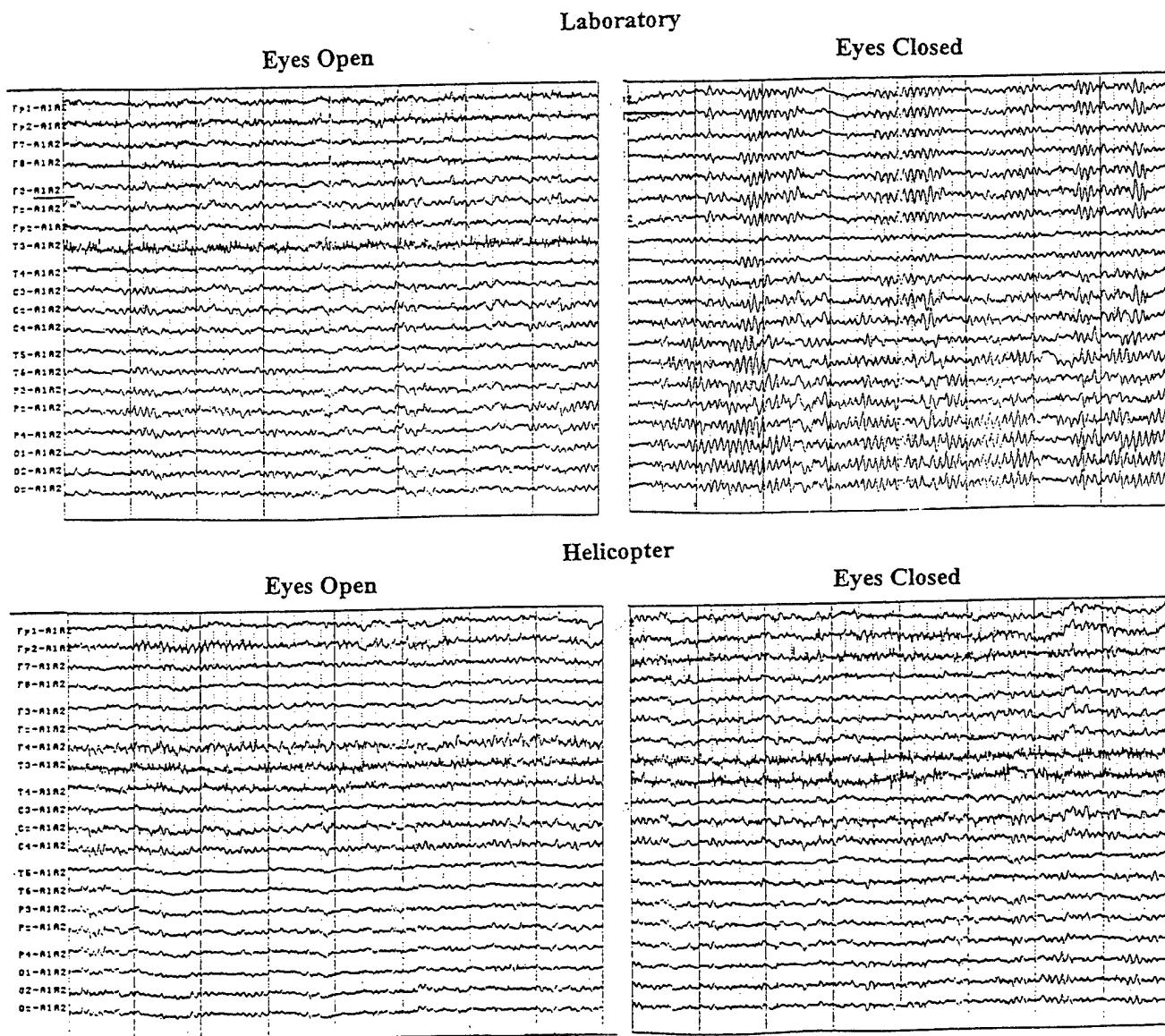


Figure A-10. An 8-second page of EEG data collected from pilot 10 collected under eyes-open and eyes-closed conditions in the helicopter and in the laboratory.

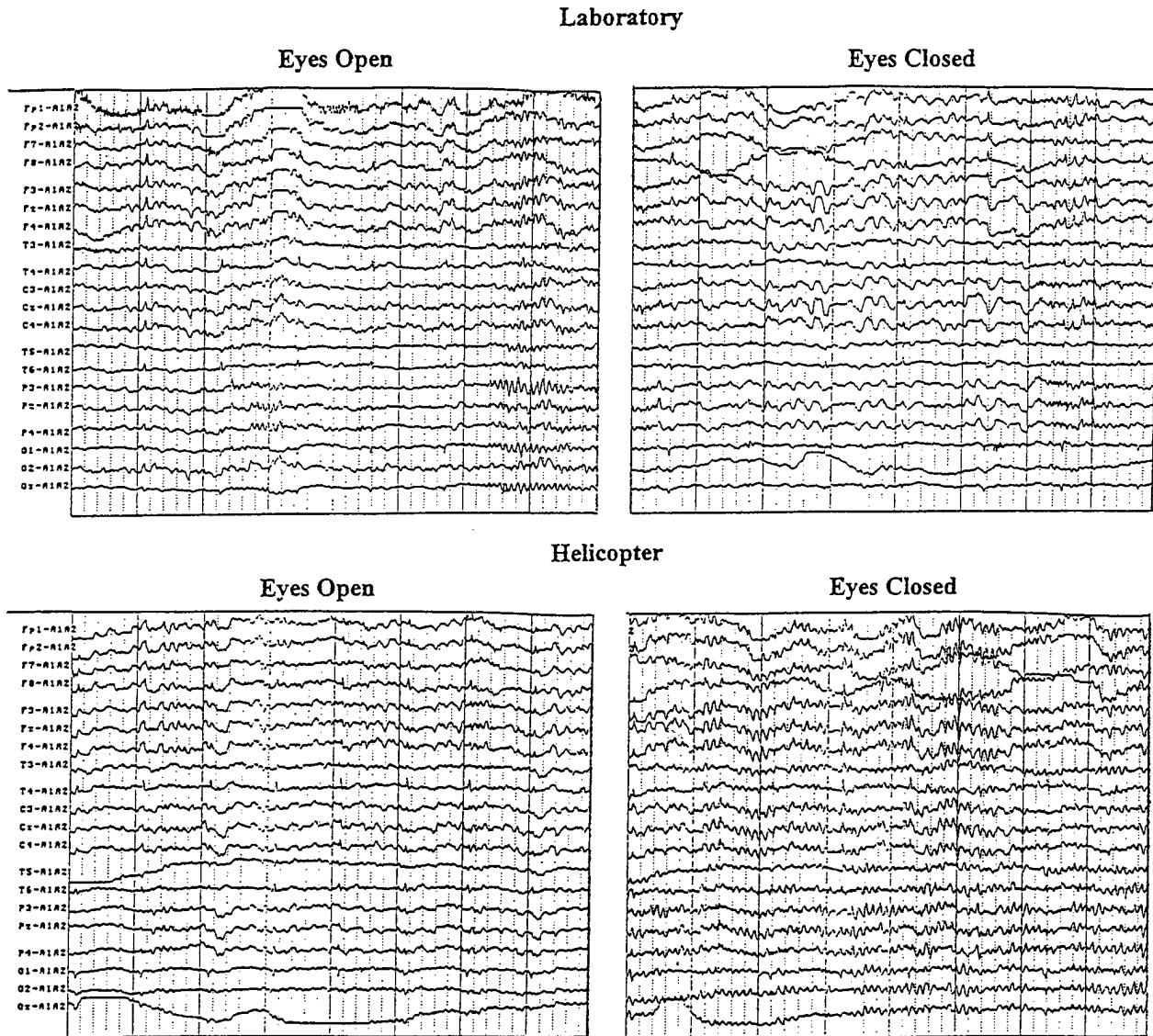


Figure A-11. An 8-second page of EEG data collected from non-pilot 1 collected under eyes-open and eyes-closed conditions in the helicopter and in the laboratory.

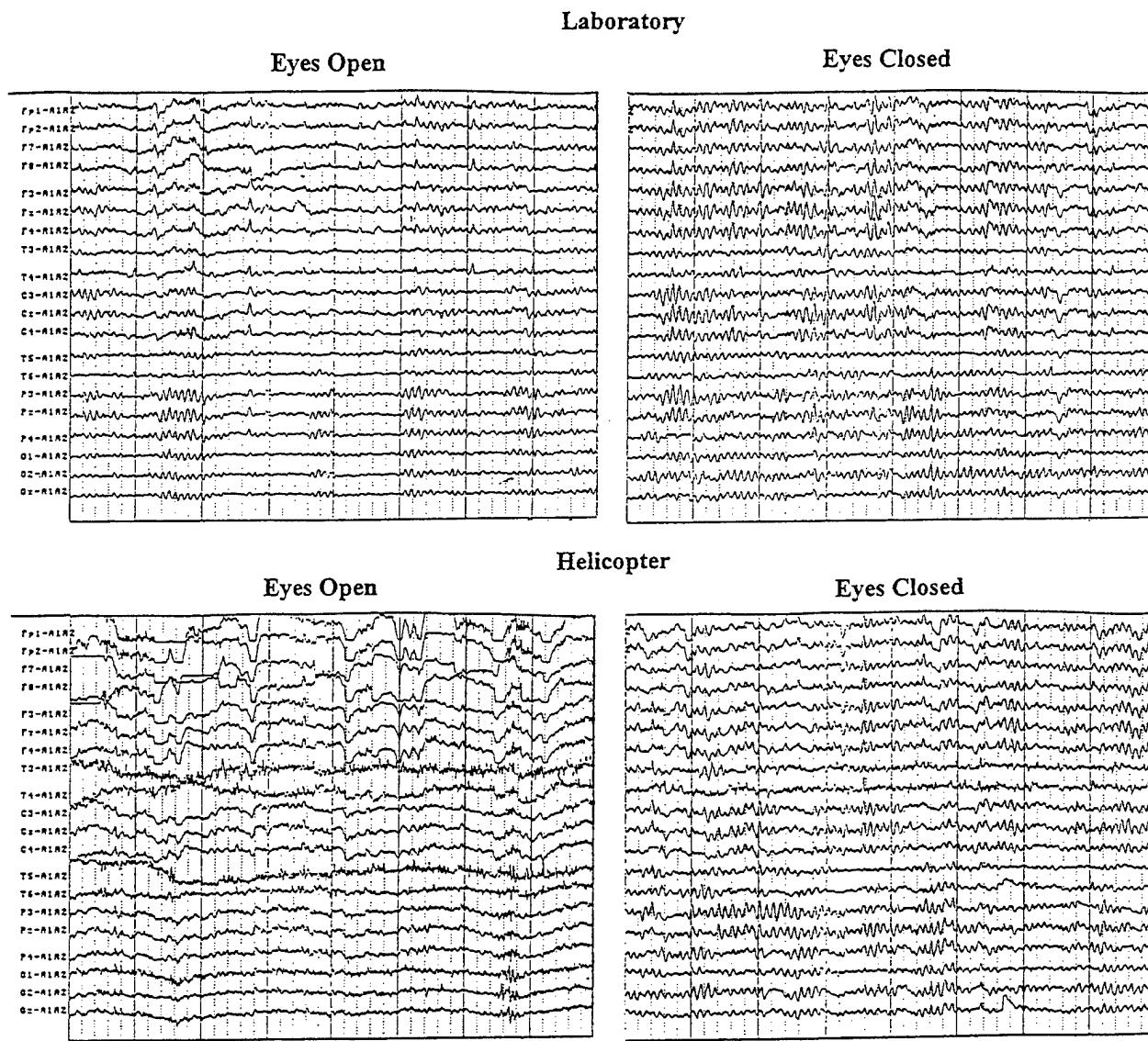


Figure A-12. An 8-second page of EEG data collected from non-pilot 2 collected under eyes-open and eyes-closed conditions in the helicopter and in the laboratory.

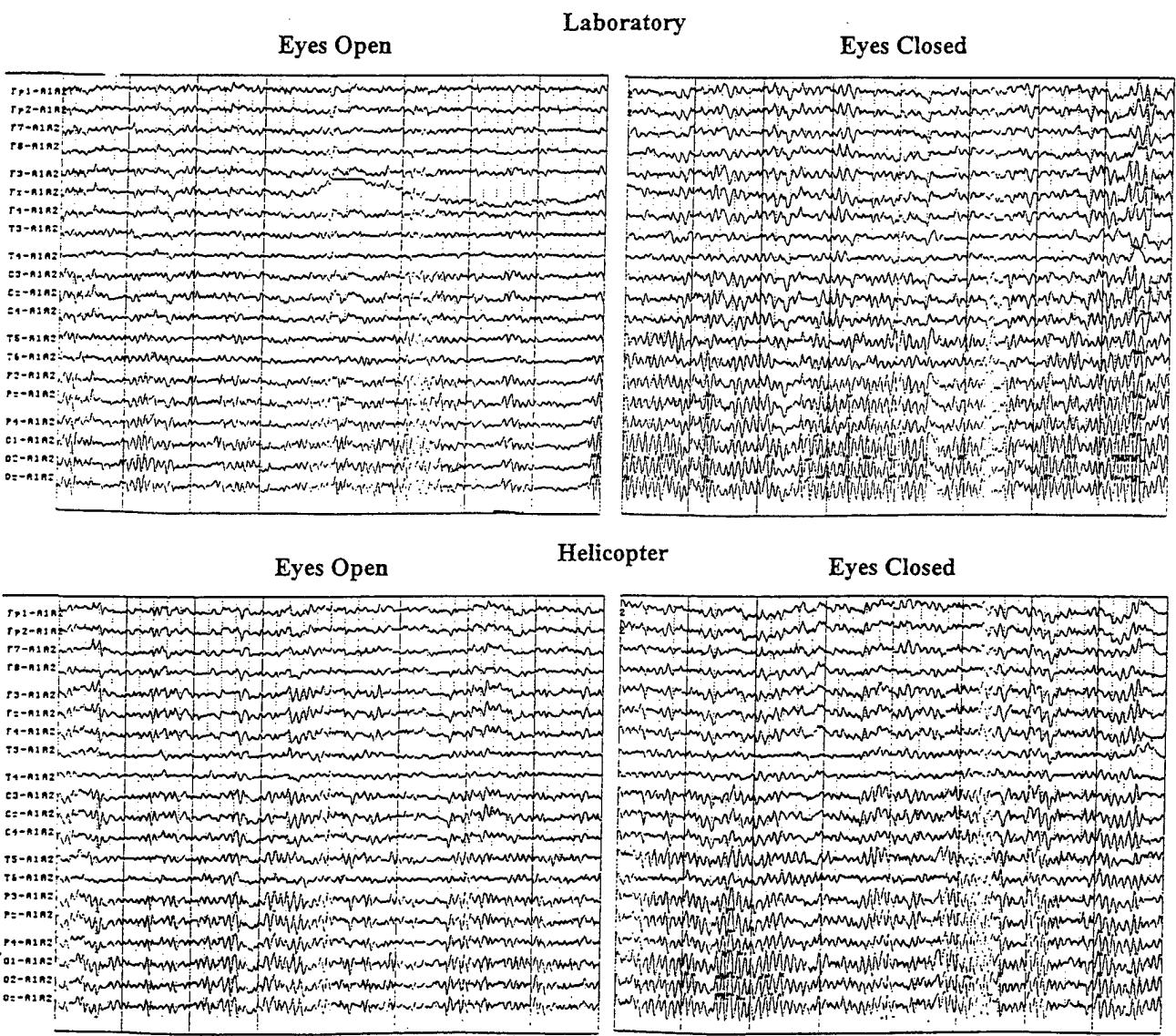


Figure A-13. An 8-second page of EEG data collected from non-pilot 3 collected under eyes-open and eyes-closed conditions in the helicopter and in the laboratory.

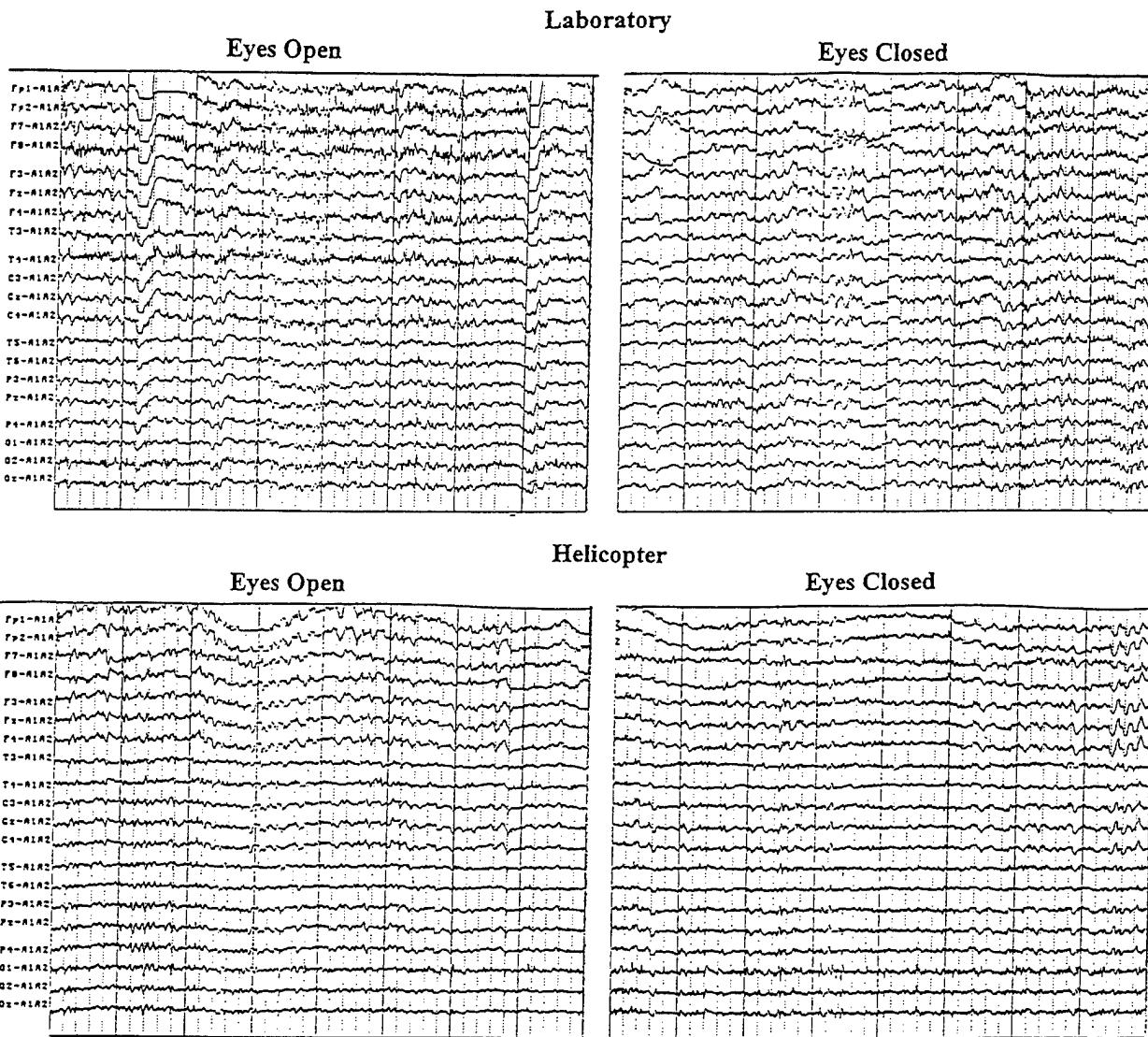


Figure A-14. An 8-second page of EEG data collected from non-pilot 4 collected under eyes-open and eyes-closed conditions in the helicopter and in the laboratory.

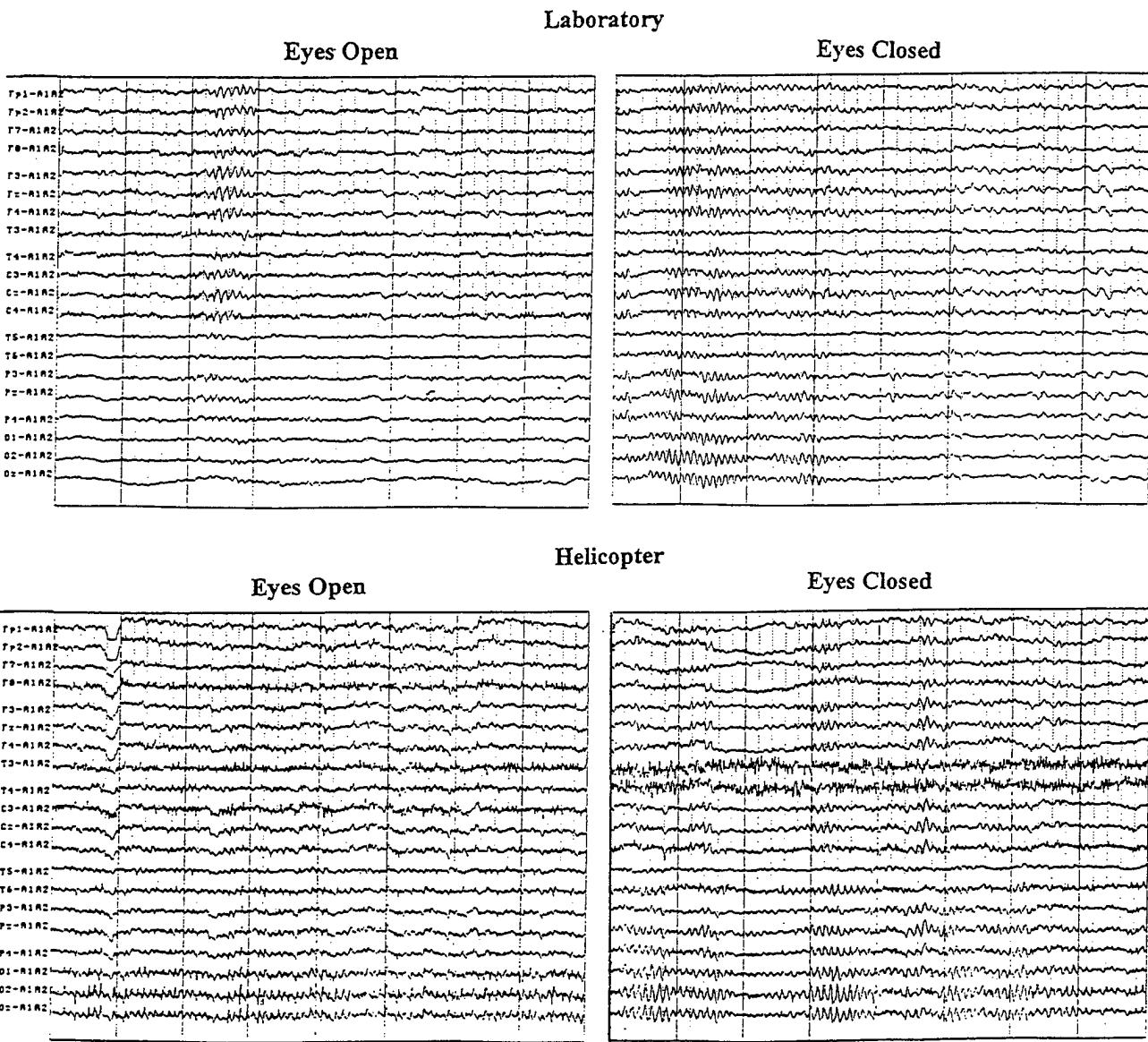


Figure A-15. An 8-second page of EEG data collected from non-pilot 5 collected under eyes-open and eyes-closed conditions in the helicopter and in the laboratory.

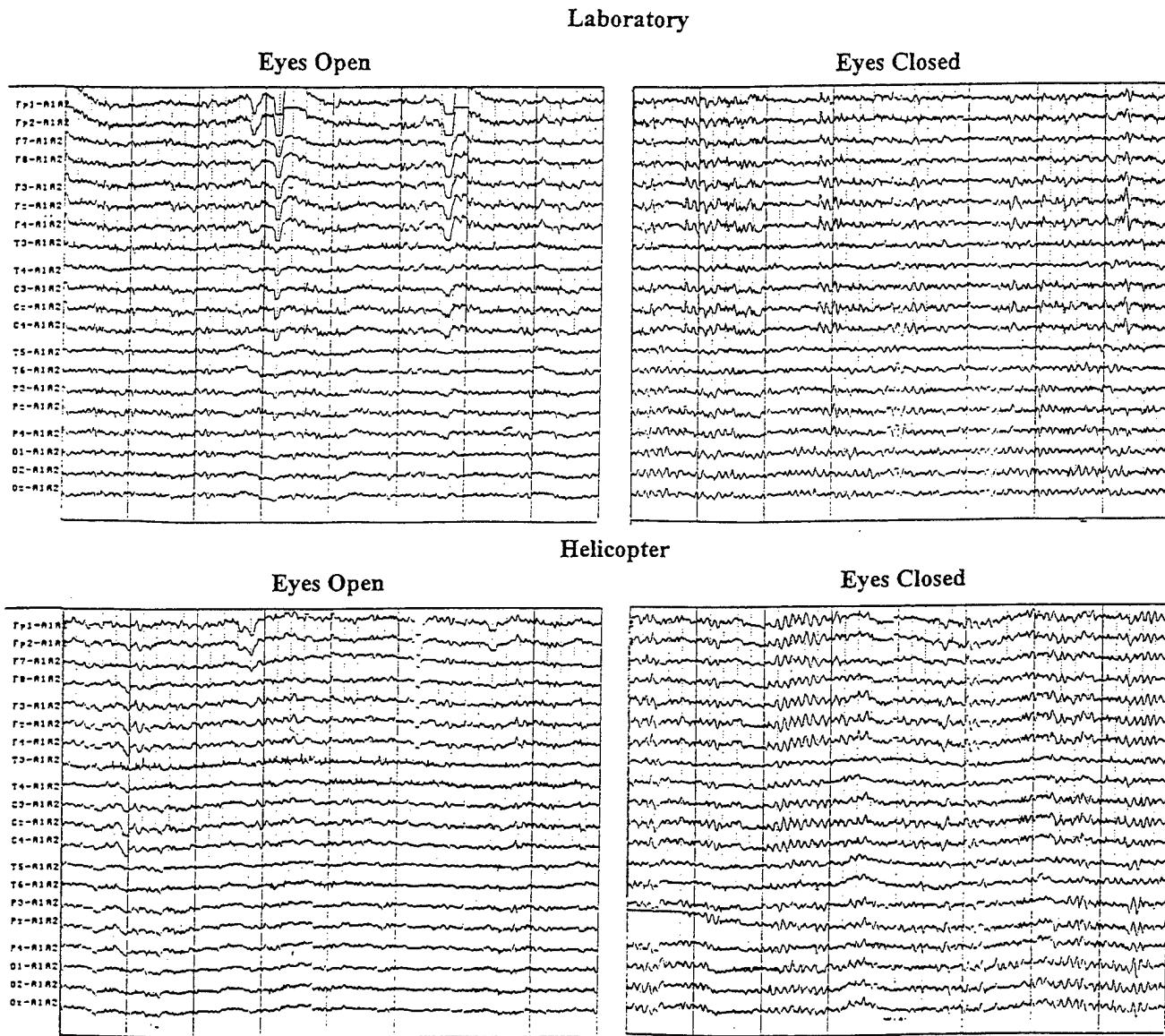


Figure A-16. An 8-second page of EEG data collected from non-pilot 6 collected under eyes-open and eyes-closed conditions in the helicopter and in the laboratory.

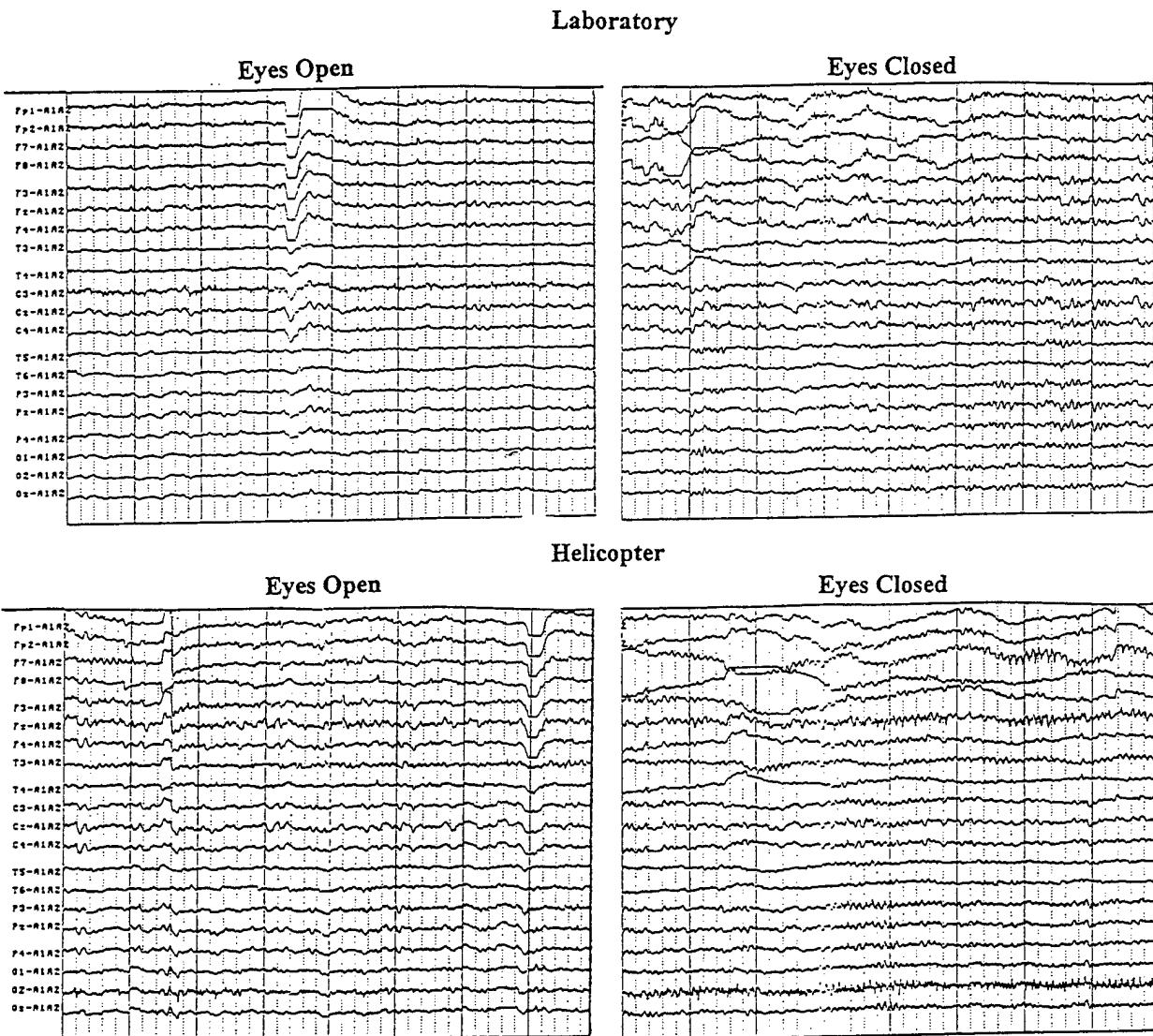
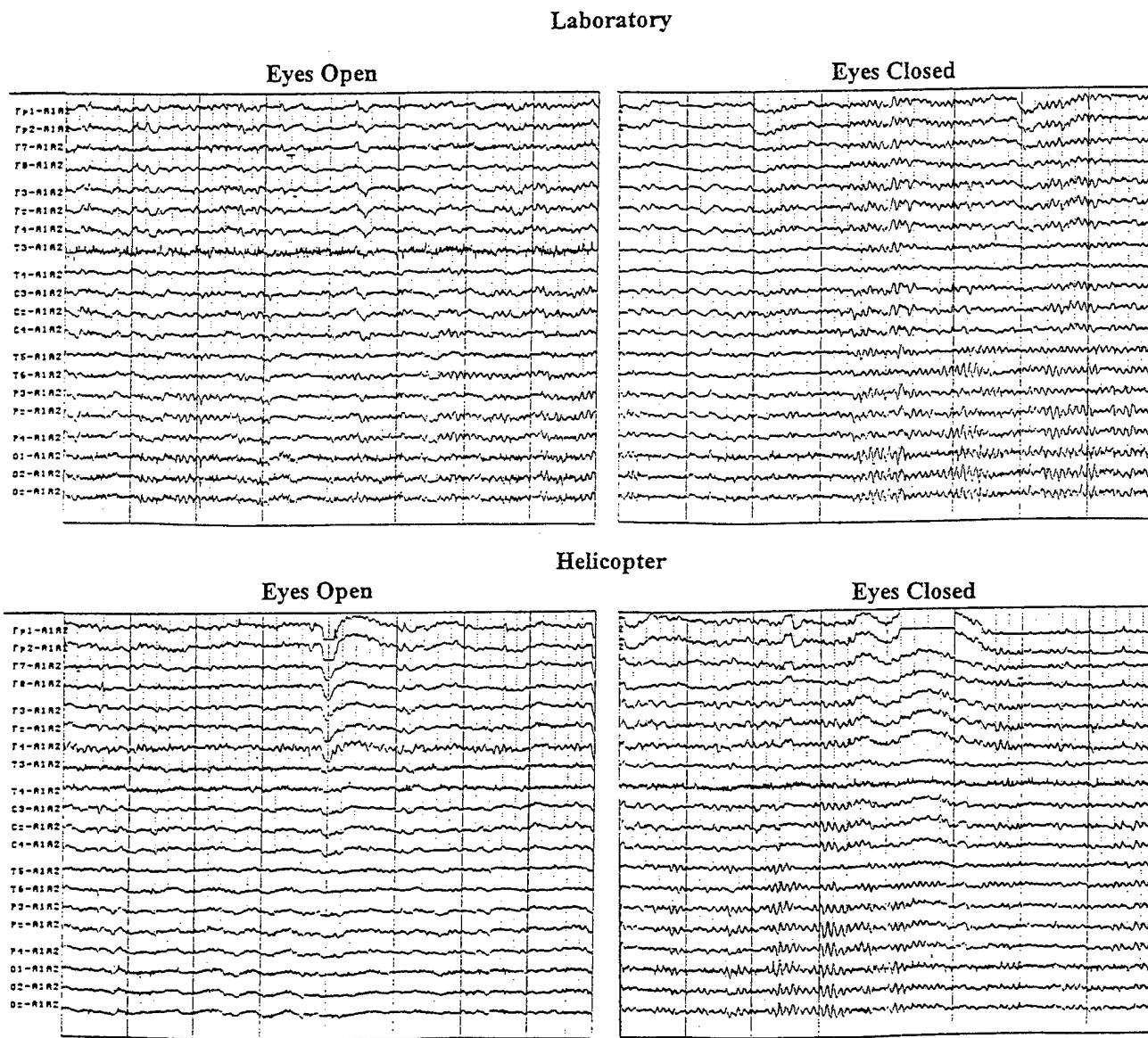


Figure A-17. An 8-second page of EEG data collected from non-pilot 7 collected under eyes-open and eyes-closed conditions in the helicopter and in the laboratory.



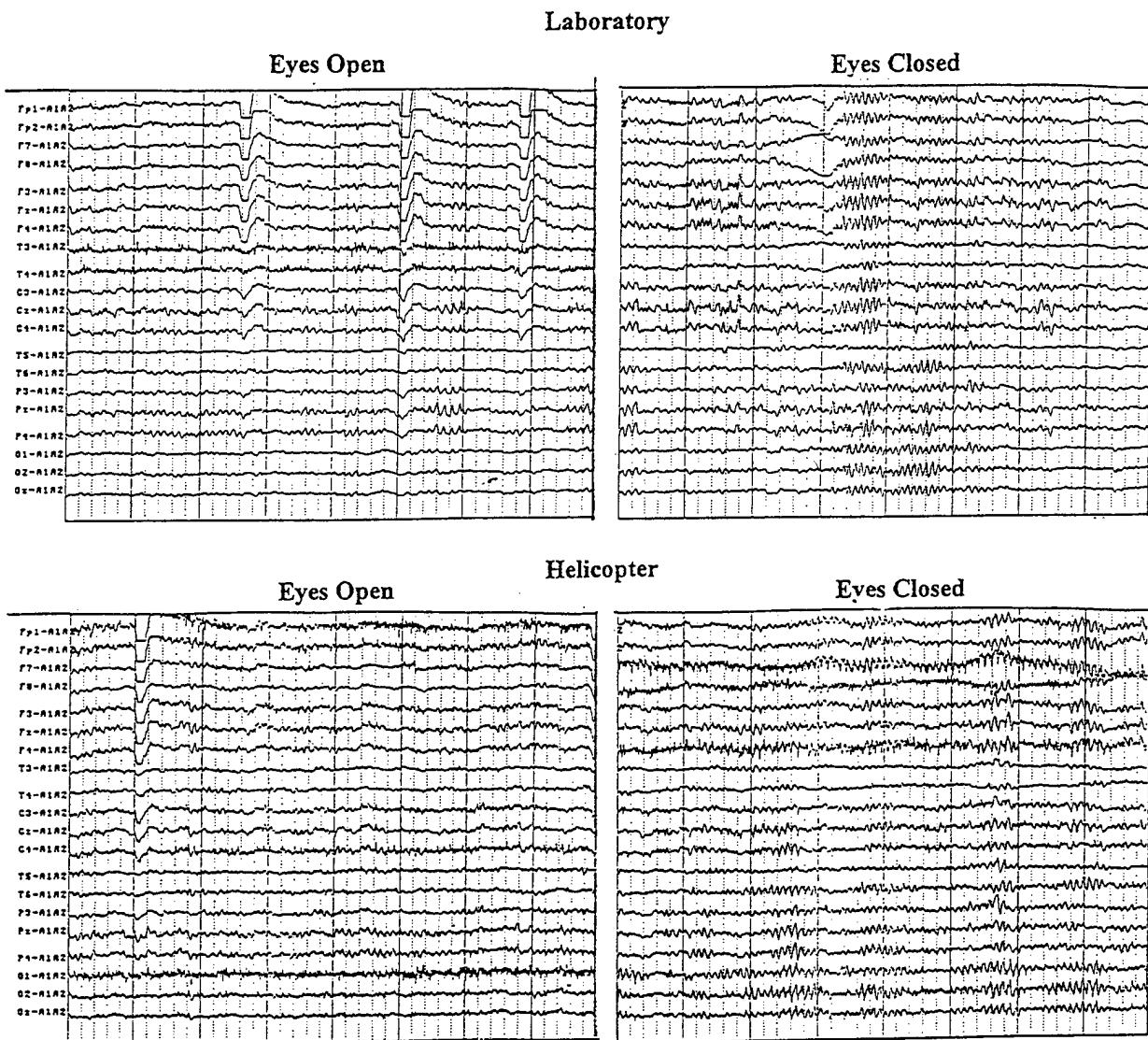


Figure A-19. An 8-second page of EEG data collected from non-pilot 9 collected under eyes-open and eyes-closed conditions in the helicopter and in the laboratory.

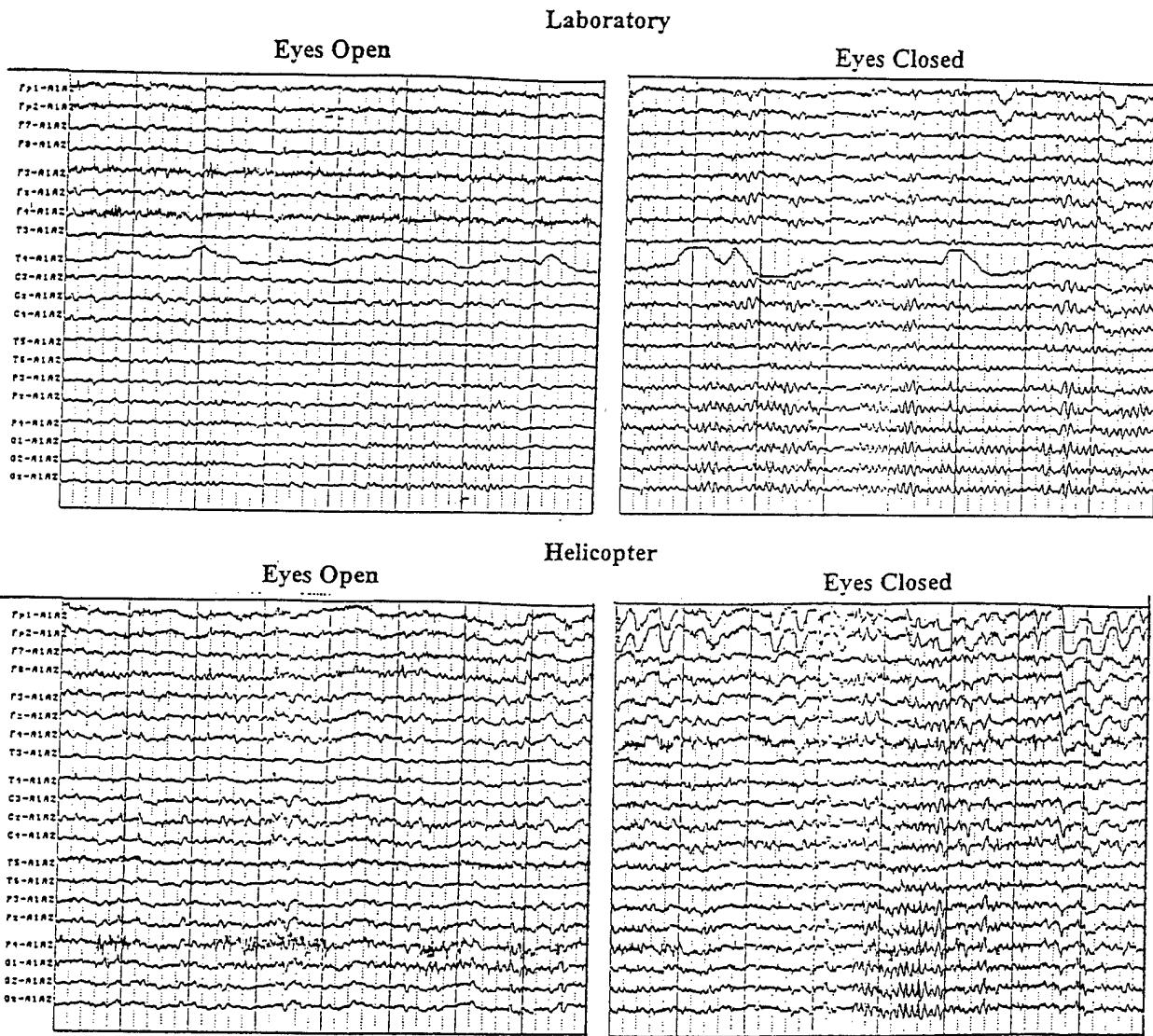


Figure A-20. An 8-second page of EEG data collected from non-pilot 10 collected under eyes-open and eyes-closed conditions in the helicopter and in the laboratory.

Part 2. Relatively artifact-free epochs for spectral analysis.

Laboratory

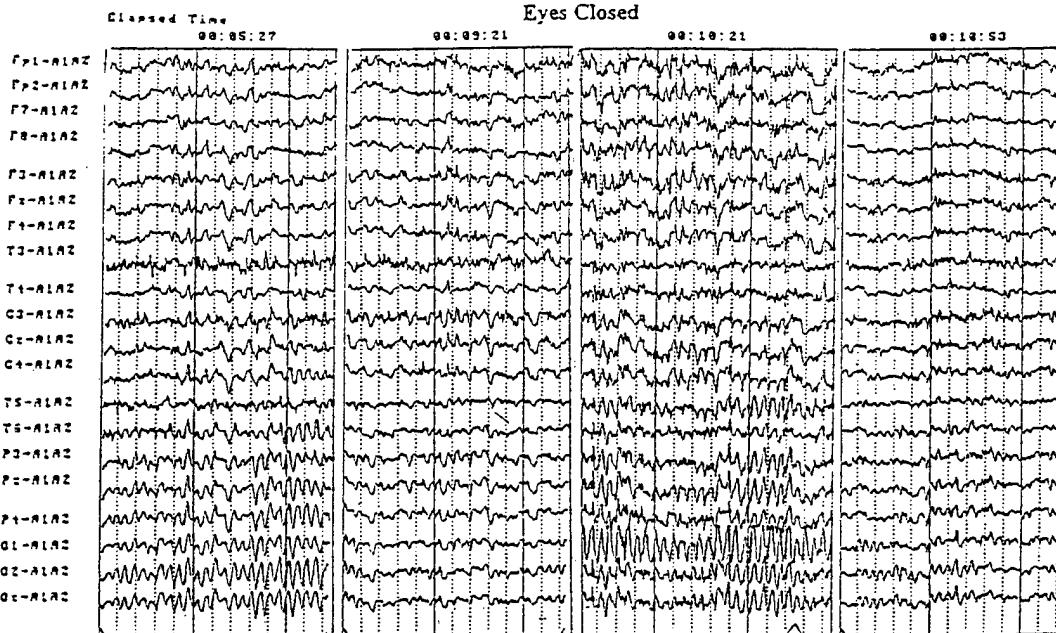
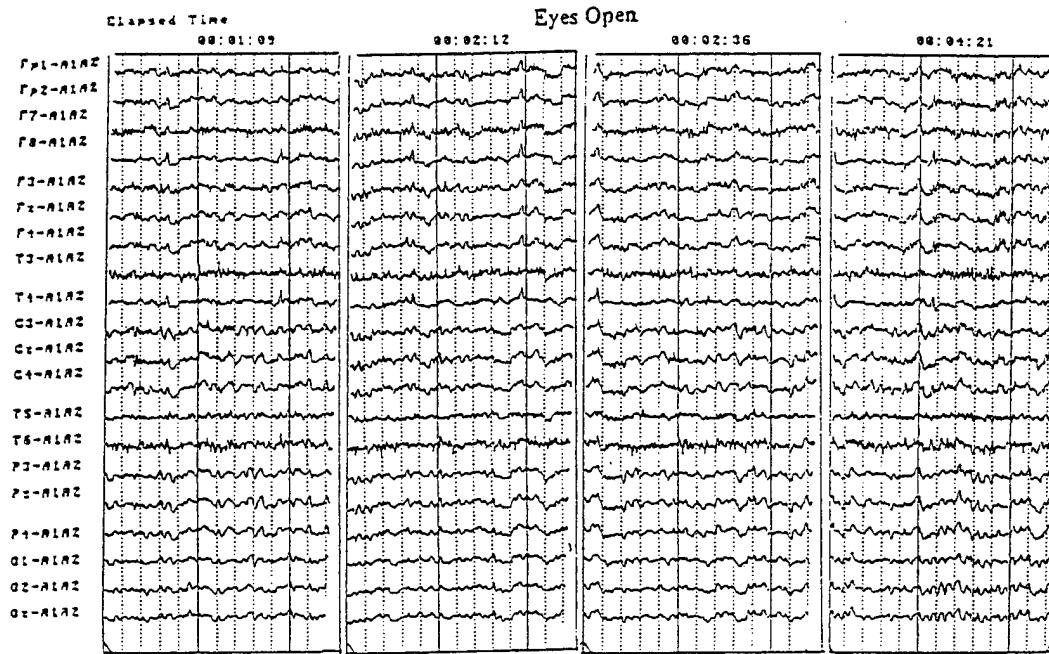


Figure A-21. The four artifact-free EEG epochs on which spectral analyses were conducted for pilot 1 in the laboratory.

**Helicopter**

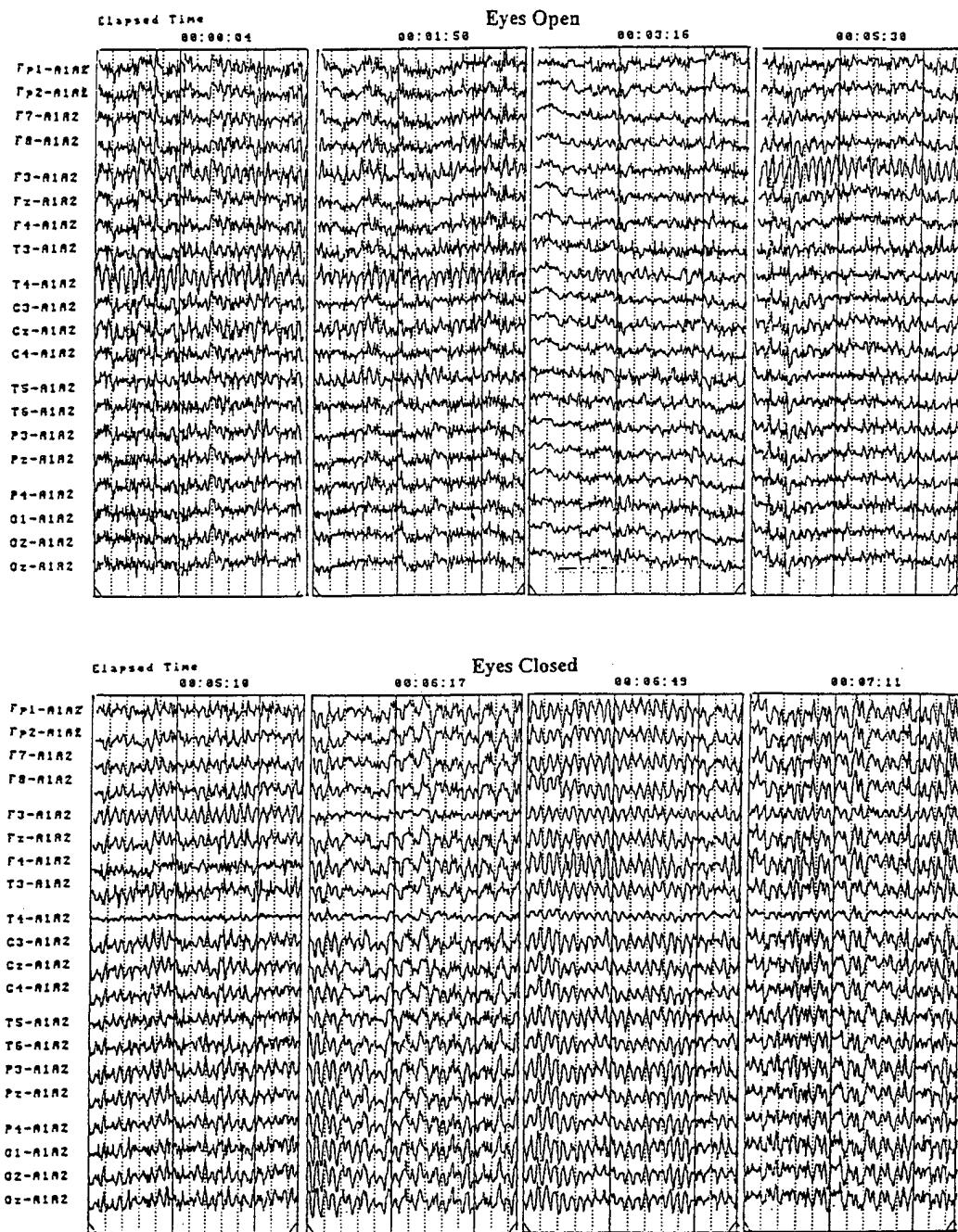


Figure A-22. The four artifact-free EEG epochs on which spectral analyses were conducted for pilot 1 in the helicopter.

Laboratory

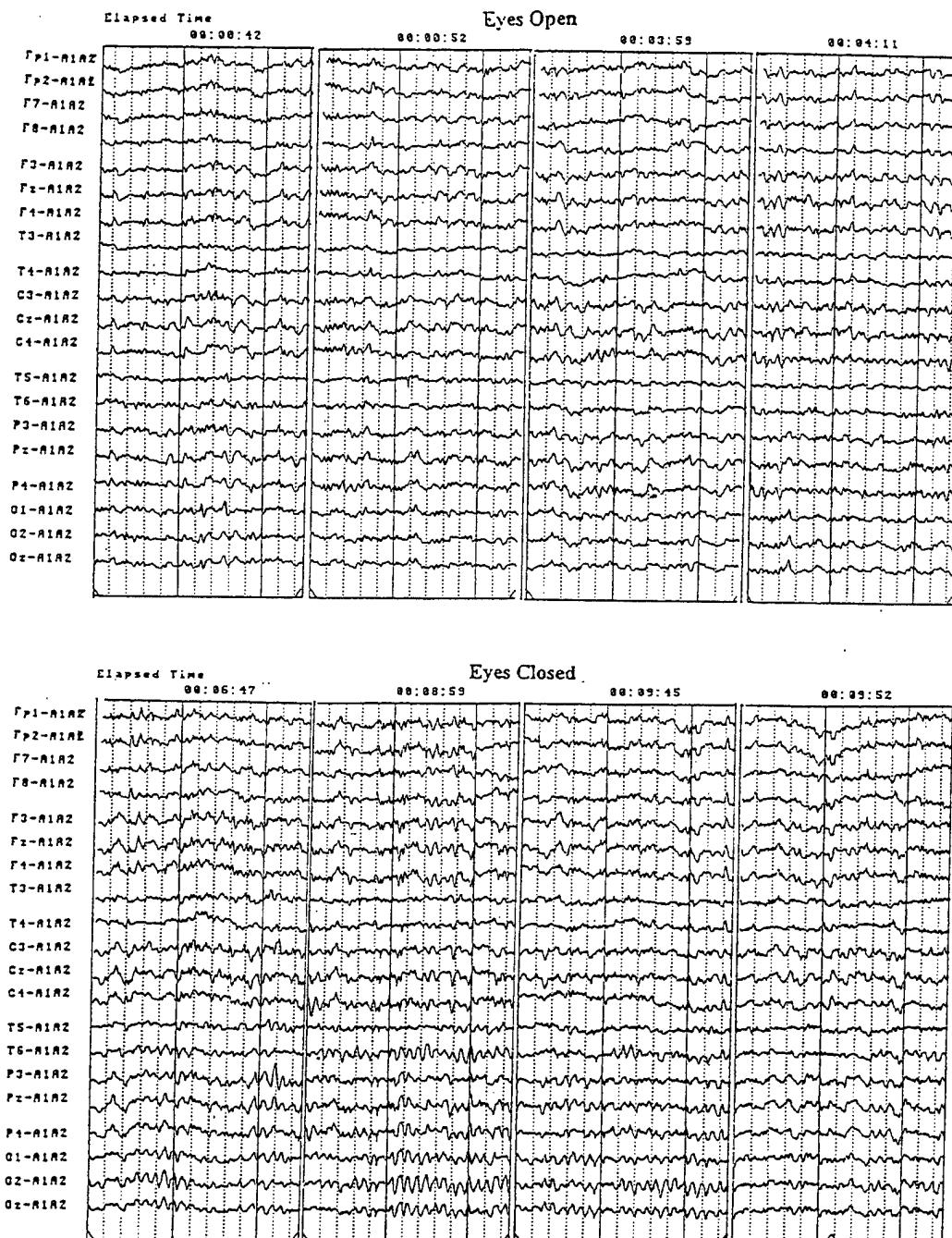


Figure A-23. The four artifact-free EEG epochs on which spectral analyses were conducted for pilot 2 in the laboratory.

**Helicopter**

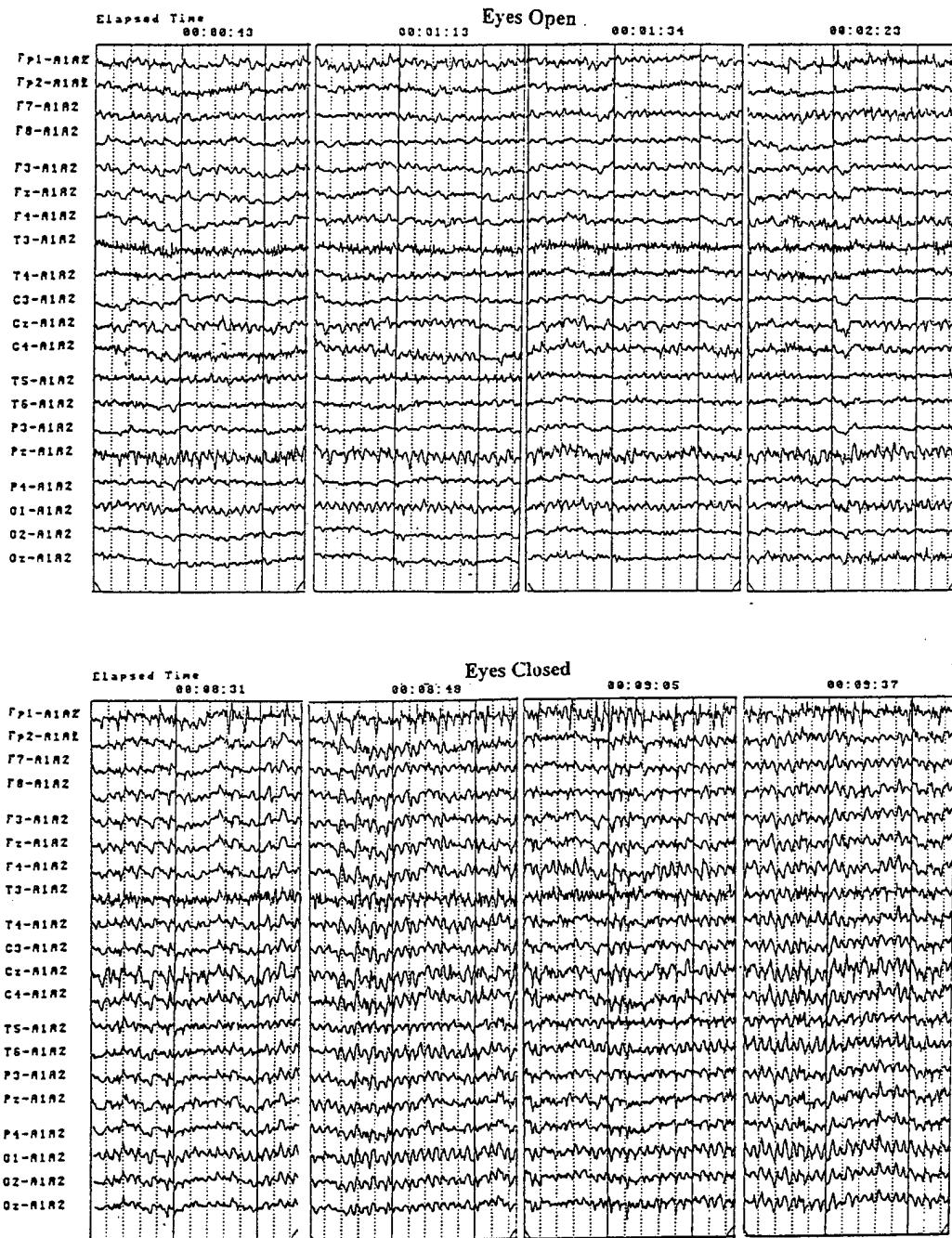


Figure A-24. The four artifact-free EEG epochs on which spectral analyses were conducted for pilot 2 in the helicopter.

Laboratory

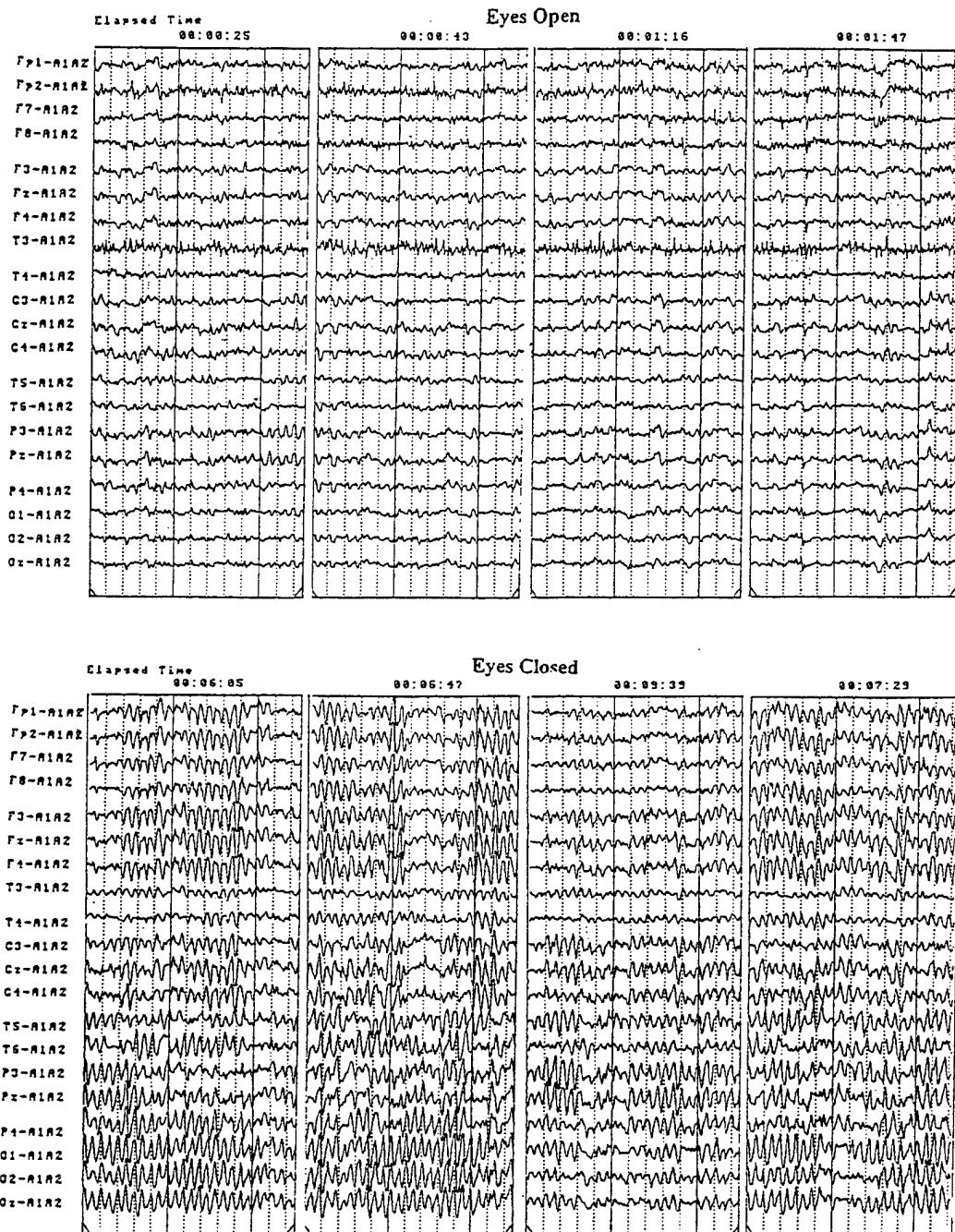


Figure A-25. The four artifact-free EEG epochs on which spectral analyses were conducted for pilot 3 in the laboratory.

**Helicopter**

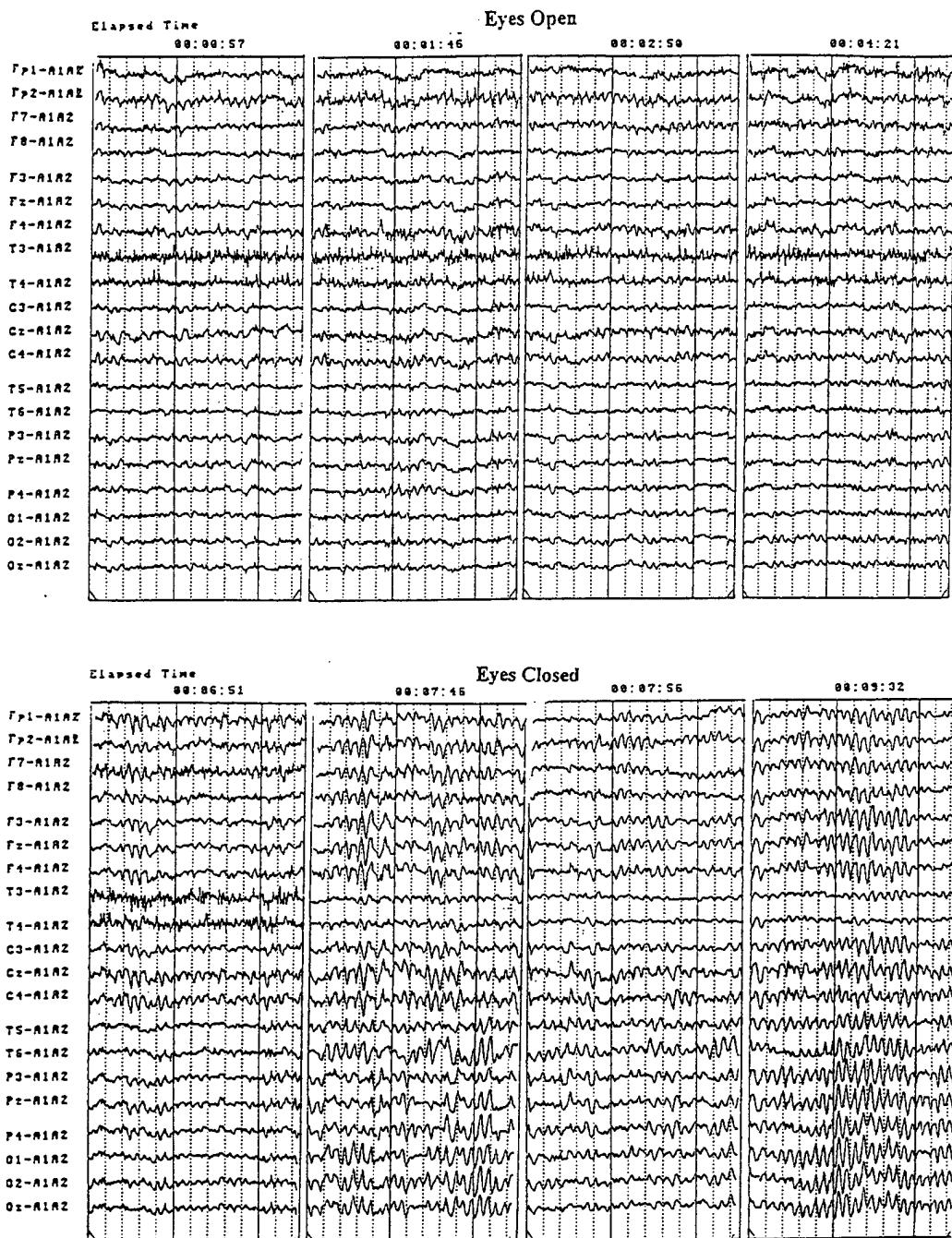


Figure A-26. The four artifact-free EEG epochs on which spectral analyses were conducted for pilot 3 in the helicopter.

Laboratory

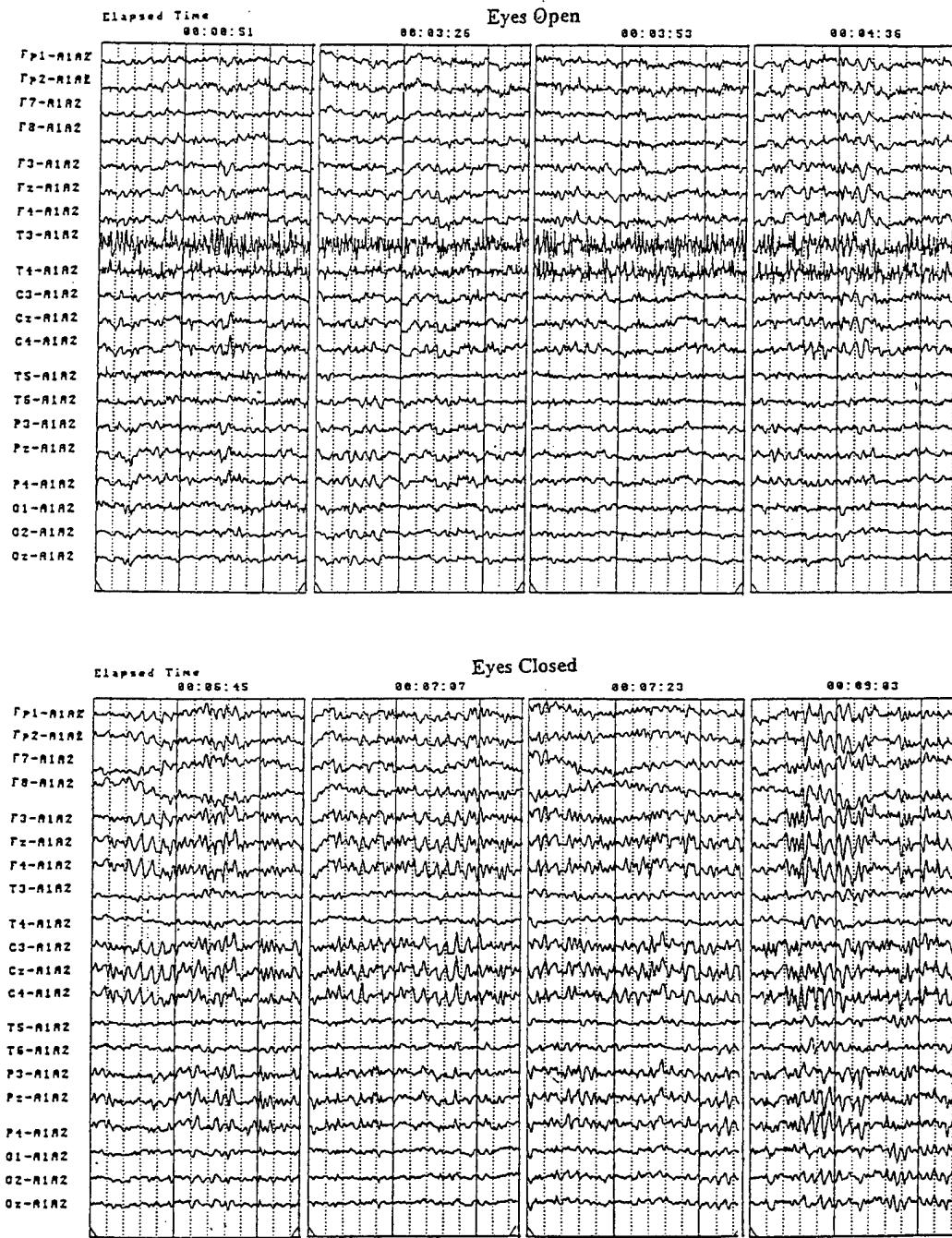


Figure A-27. The four artifact-free EEG epochs on which spectral analyses were conducted for pilot 4 in the laboratory.

**Helicopter**

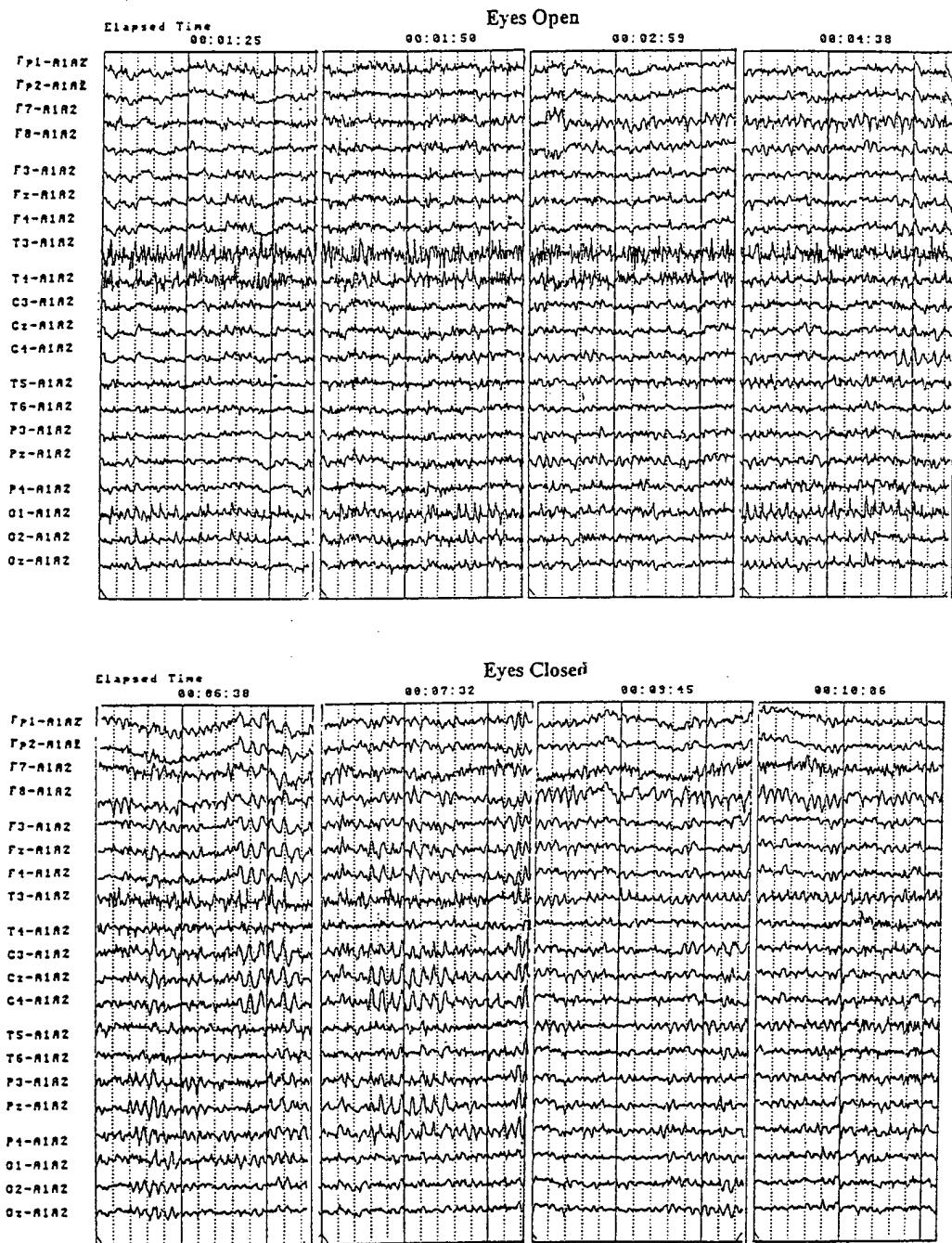


Figure A-28. The four artifact-free EEG epochs on which spectral analyses were conducted for pilot 4 in the helicopter.

Laboratory

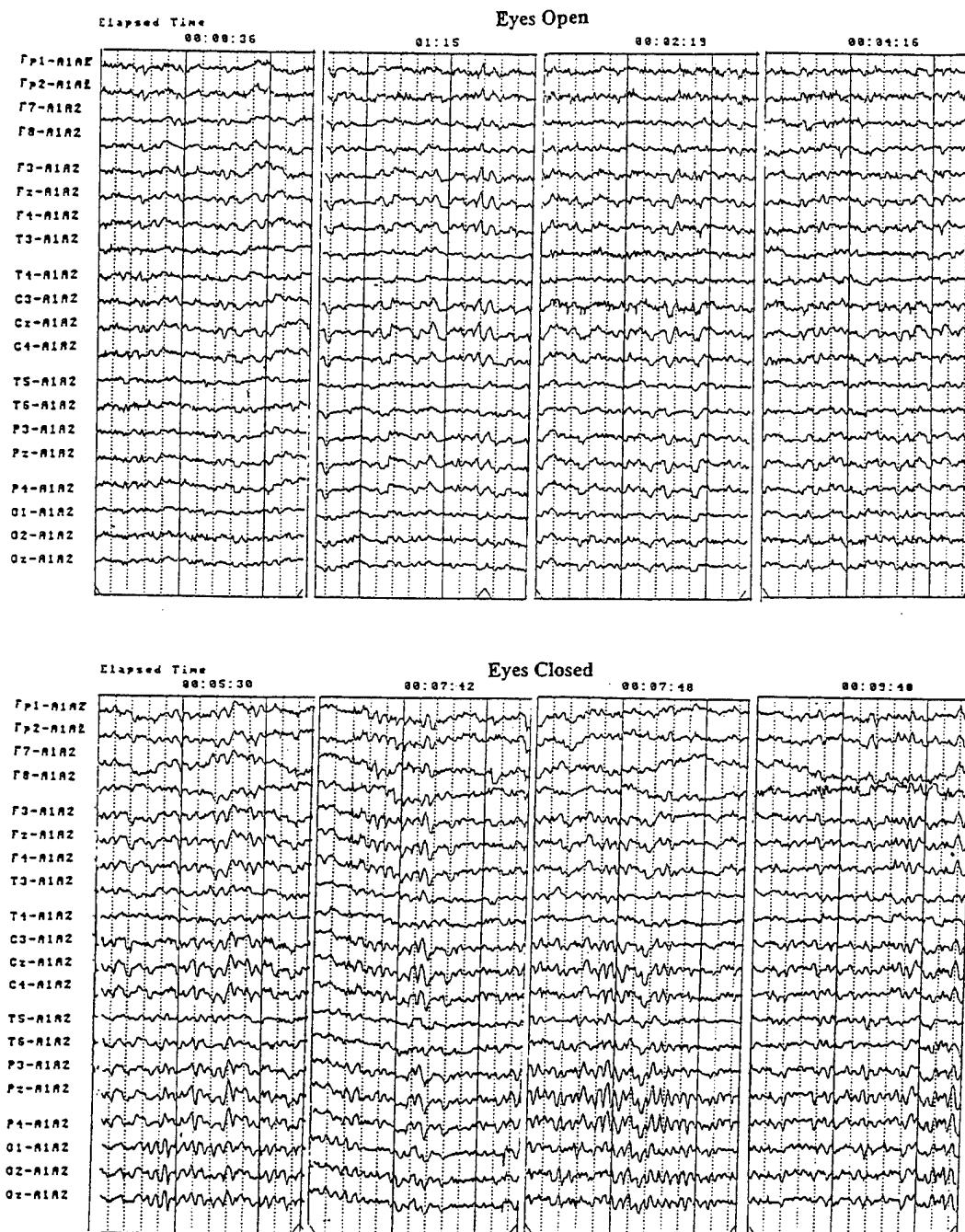


Figure A-29. The four artifact-free EEG epochs on which spectral analyses were conducted for pilot 5 in the laboratory.

**Helicopter**

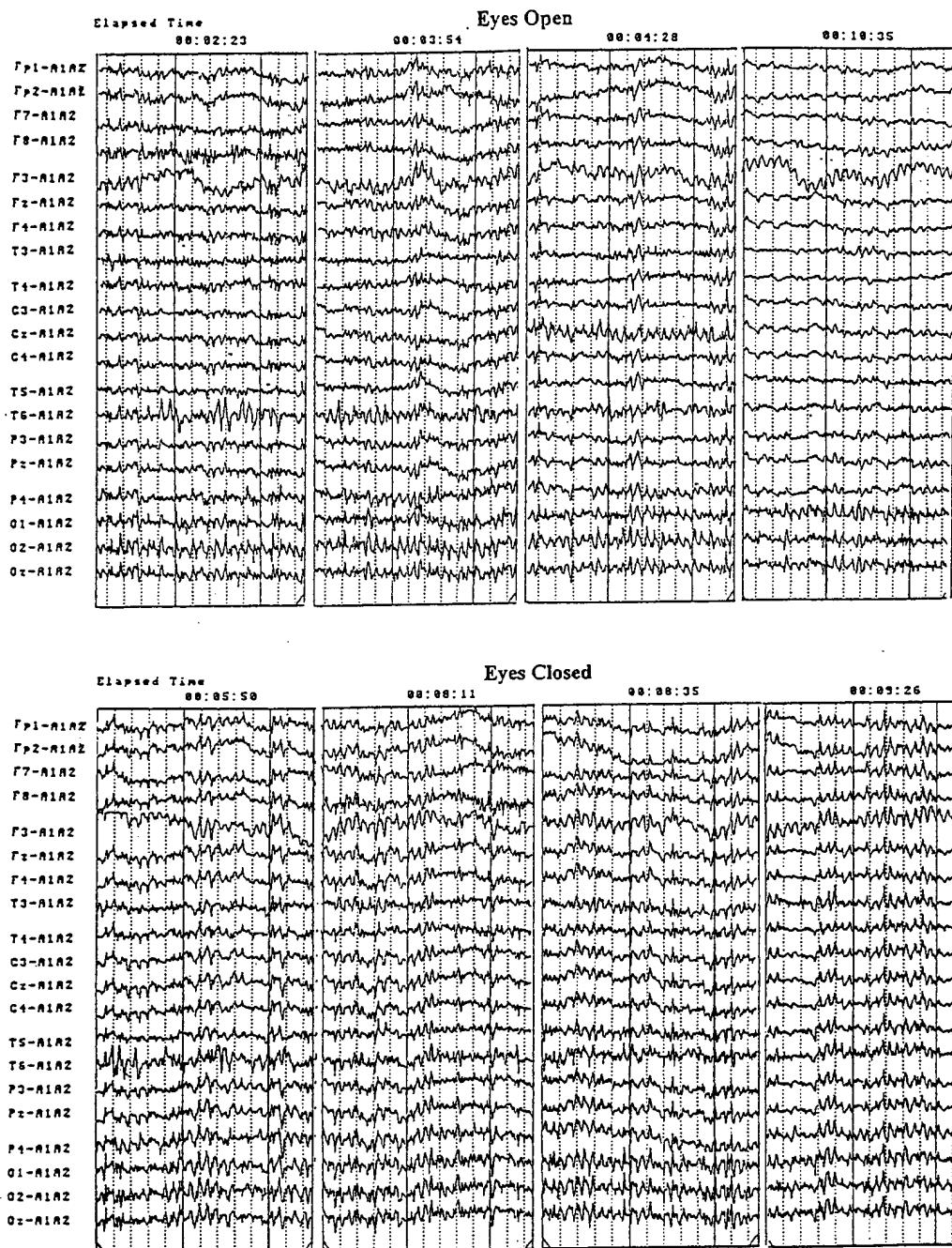


Figure A-30. The four artifact-free EEG epochs on which spectral analyses were conducted for pilot 5 in the helicopter.

Laboratory

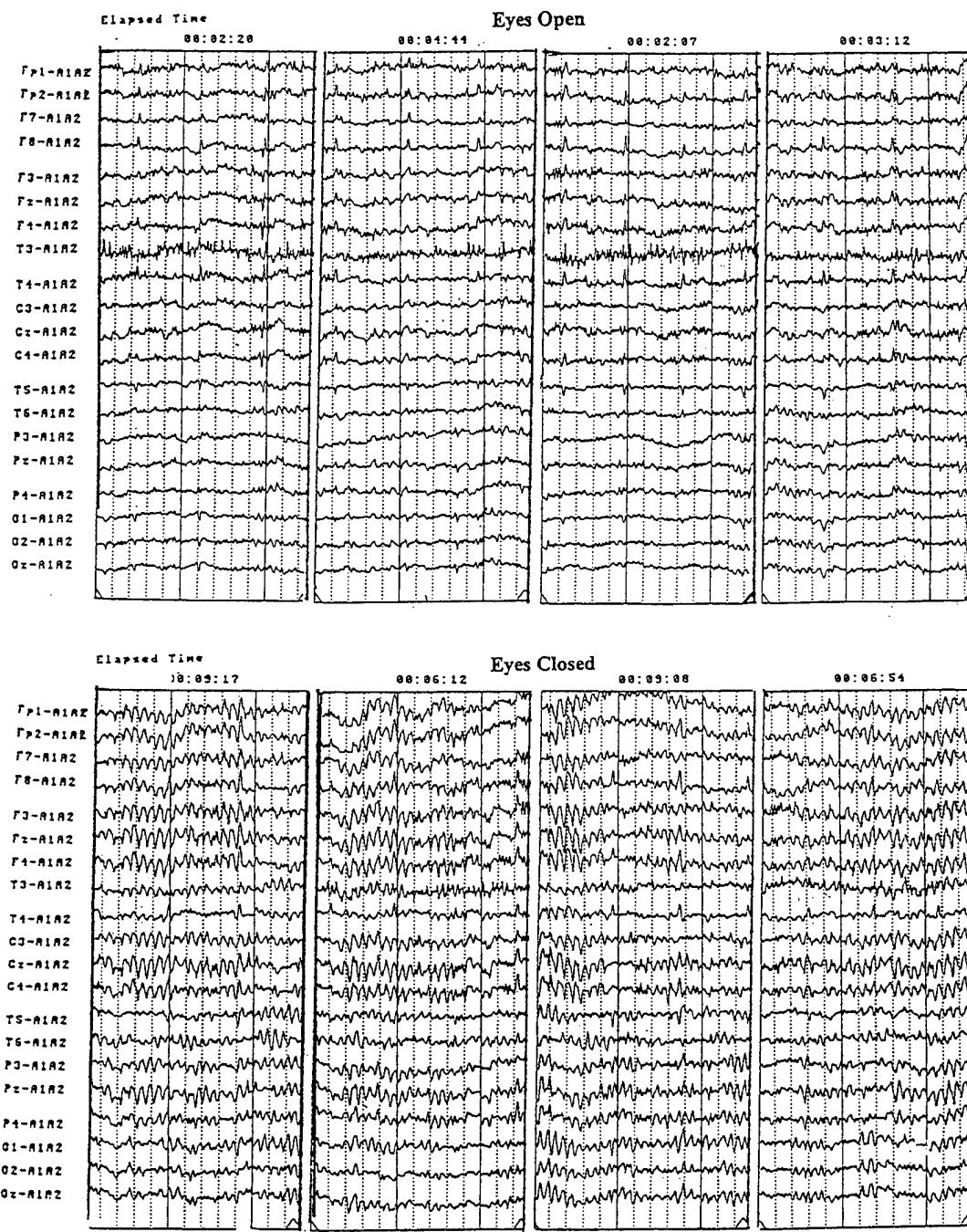


Figure A-31. The four artifact-free EEG epochs on which spectral analyses were conducted for pilot 6 in the laboratory.

**Helicopter**

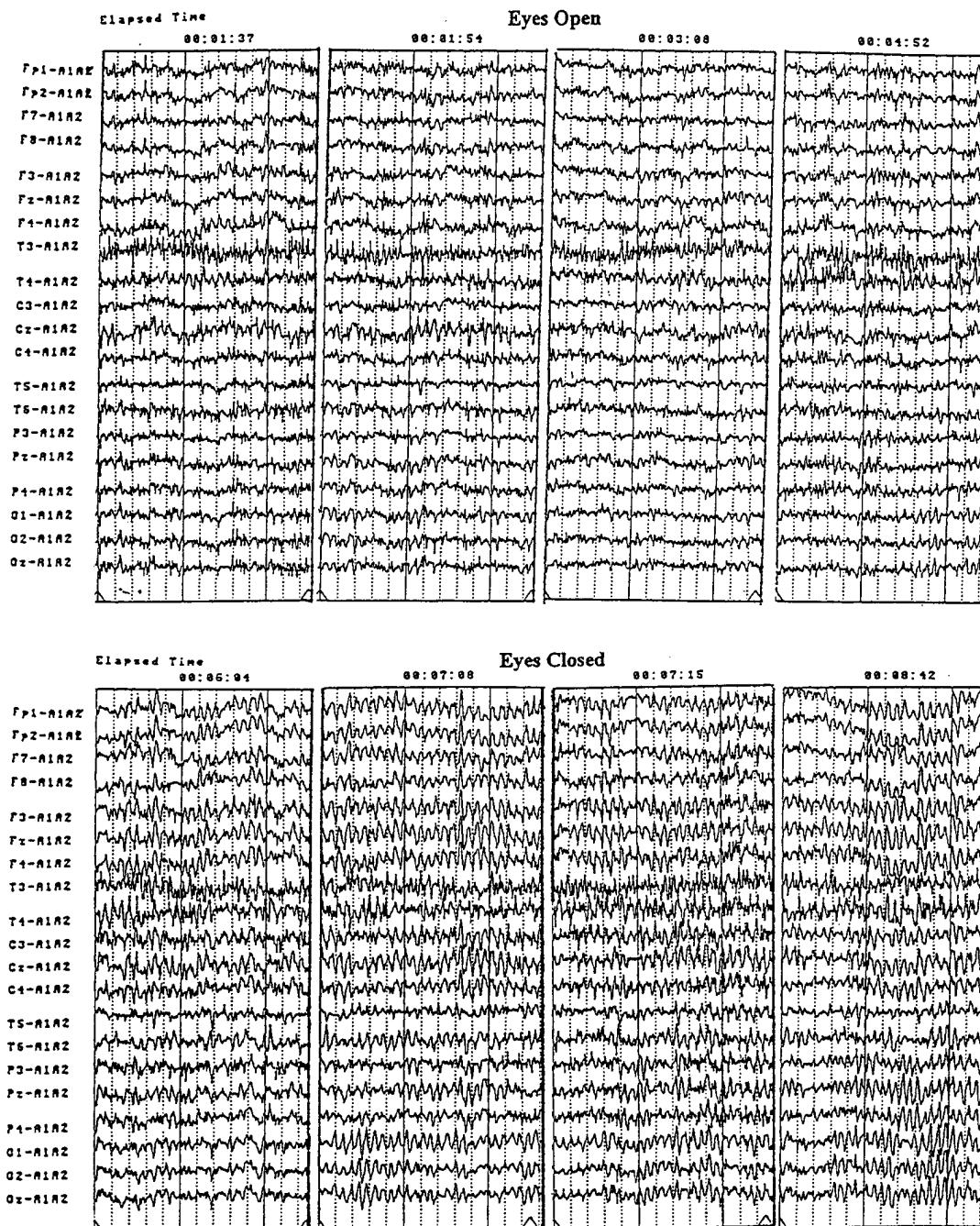


Figure A-32. The four artifact-free EEG epochs on which spectral analyses were conducted for pilot 6 in the helicopter.

Laboratory

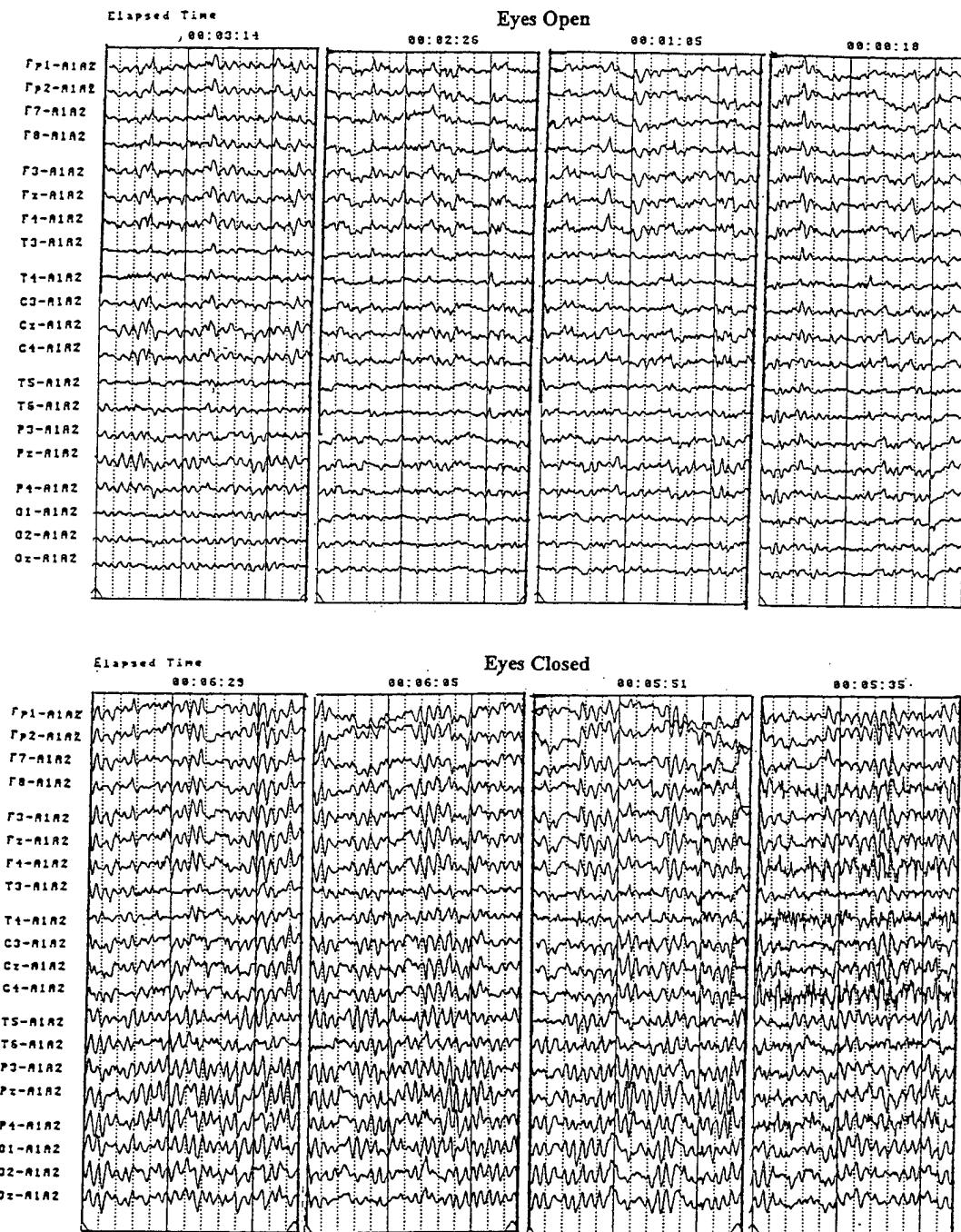


Figure A-33. The four artifact-free EEG epochs on which spectral analyses were conducted for pilot 7 in the laboratory.

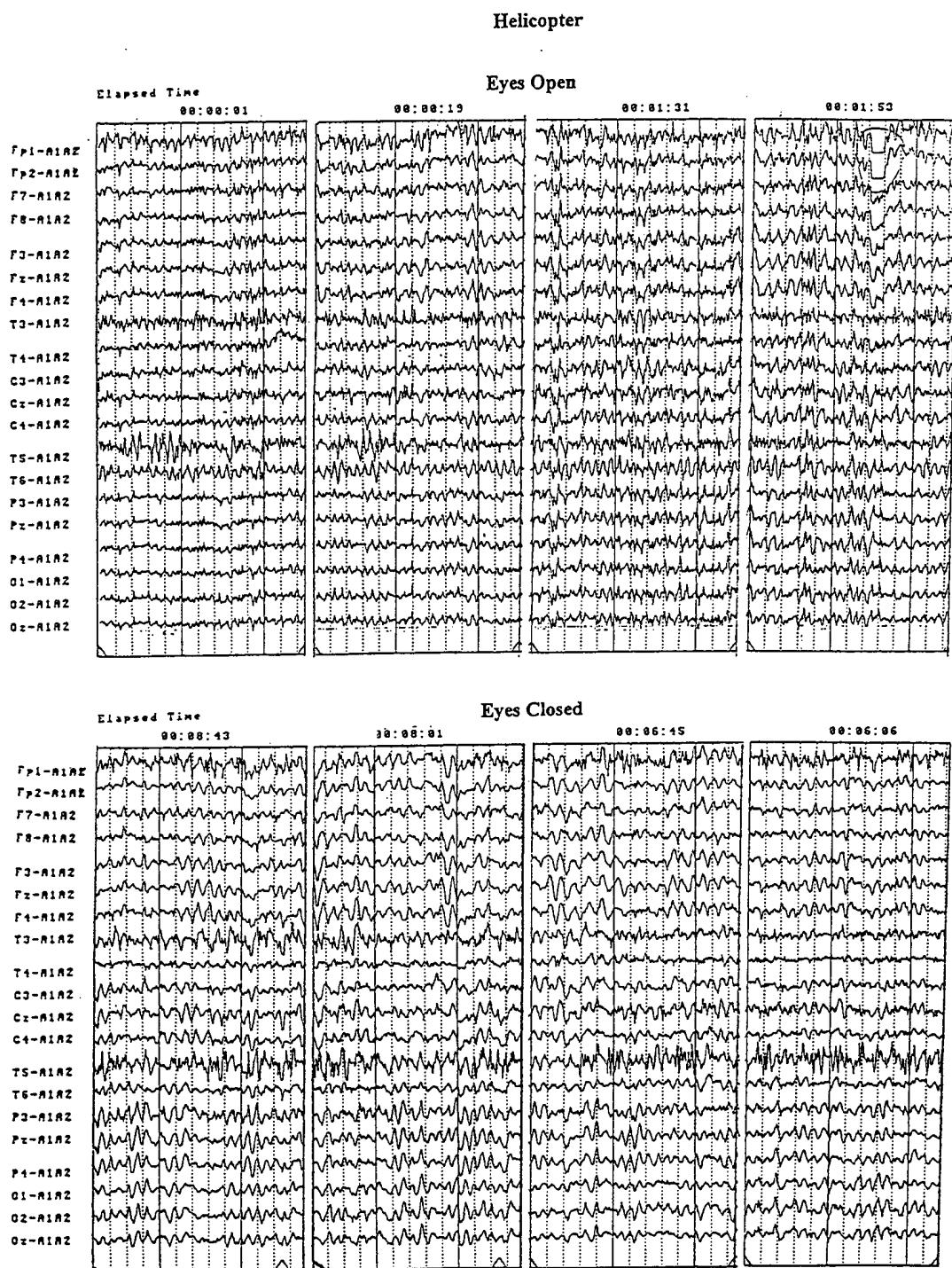


Figure A-34. The four artifact-free EEG epochs on which spectral analyses were conducted for pilot 7 in the helicopter.

Laboratory

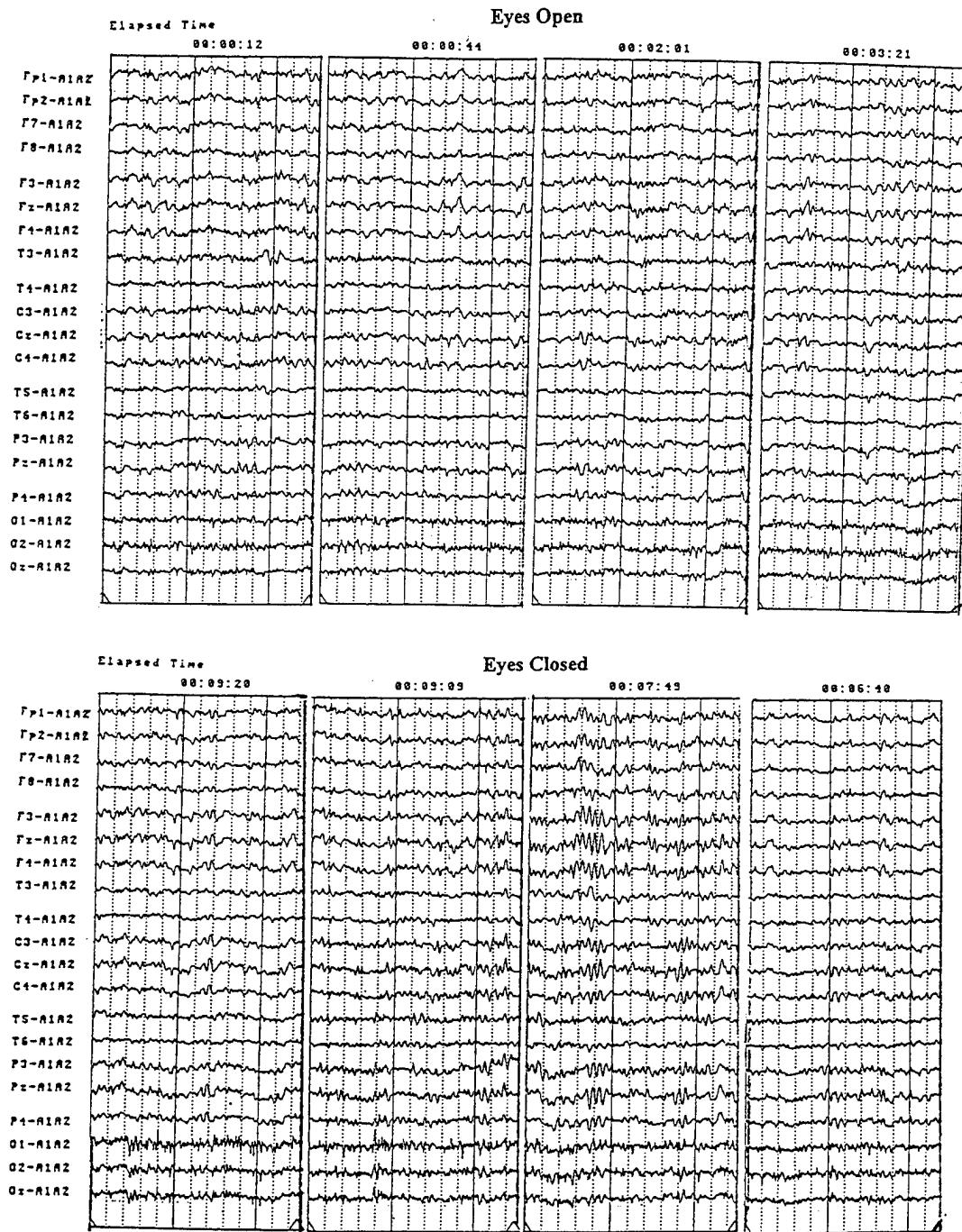


Figure A-35. The four artifact-free EEG epochs on which spectral analyses were conducted for pilot 8 in the laboratory.

**Helicopter**

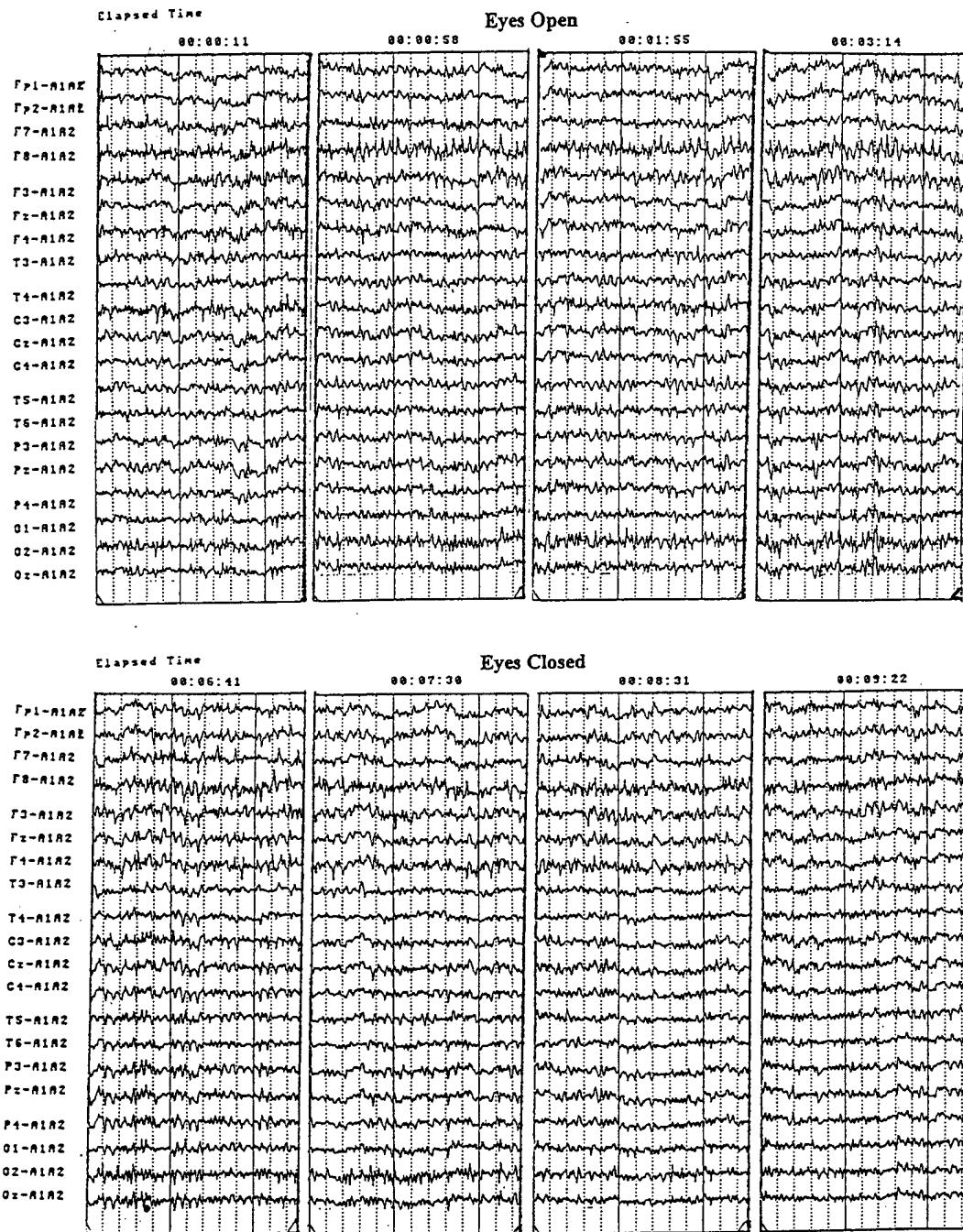


Figure A-36. The four artifact-free EEG epochs on which spectral analyses were conducted for pilot 8 in the helicopter.

Laboratory

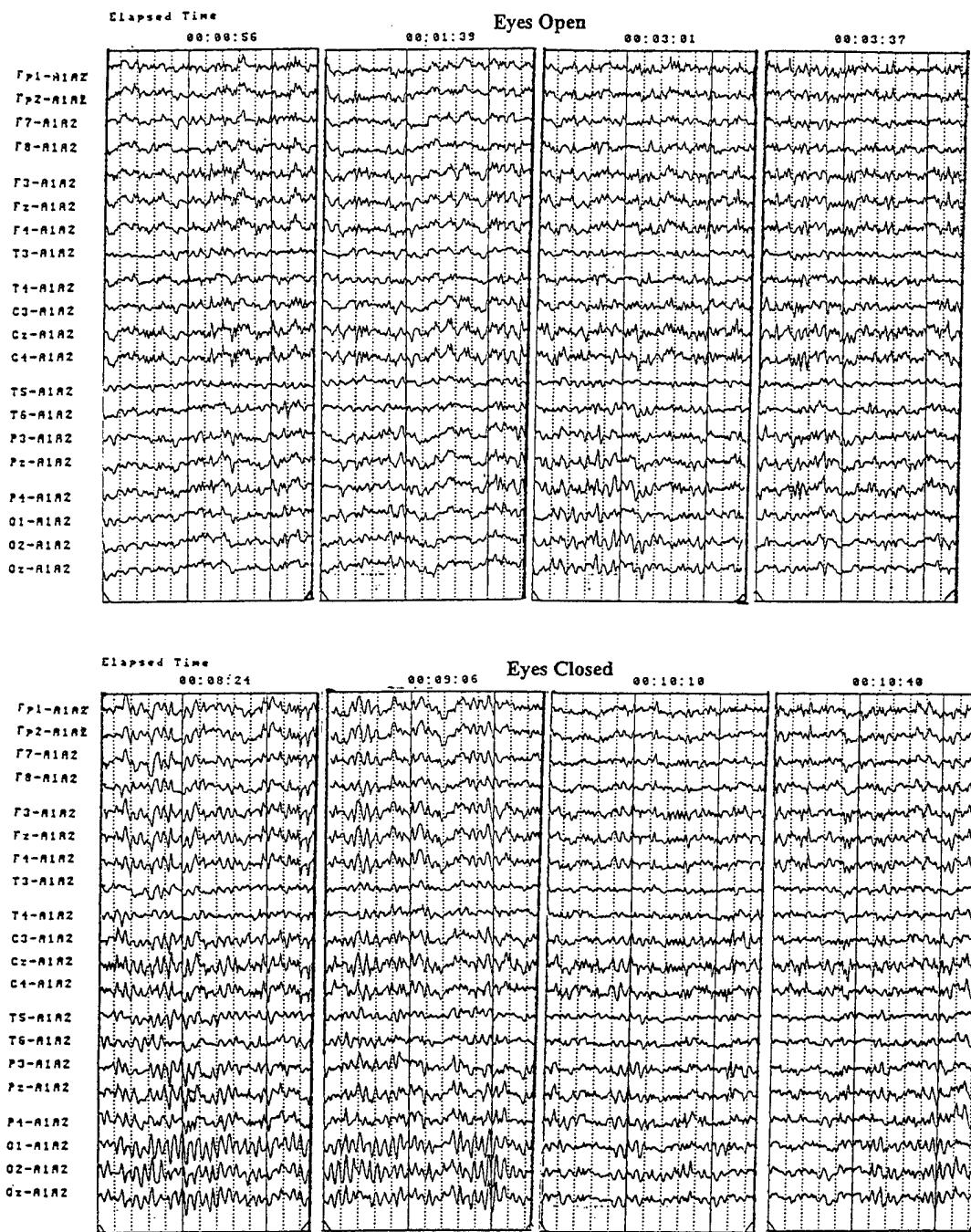


Figure A-37. The four artifact-free EEG epochs on which spectral analyses were conducted for pilot 9 in the laboratory.

**Helicopter**

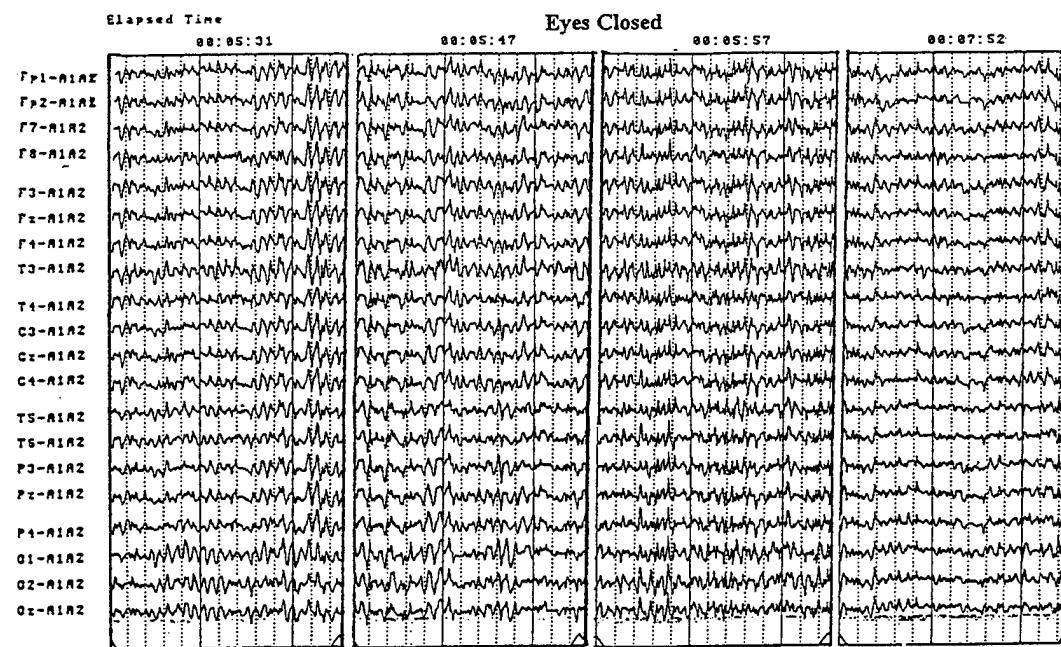
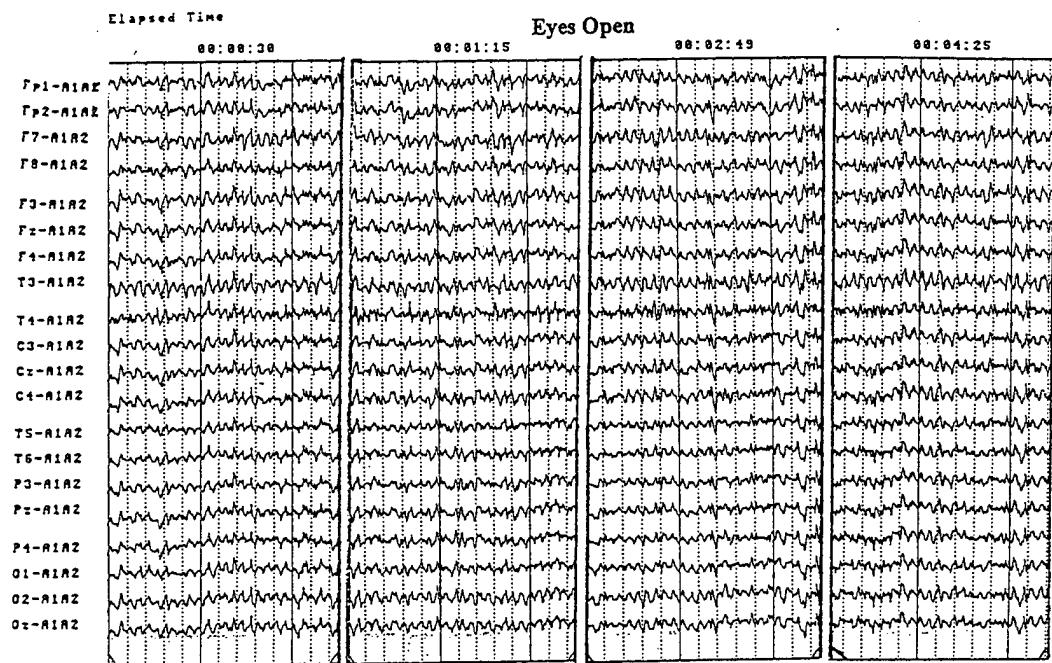


Figure A-38. The four artifact-free EEG epochs on which spectral analyses were conducted for pilot 9 in the helicopter.

Laboratory

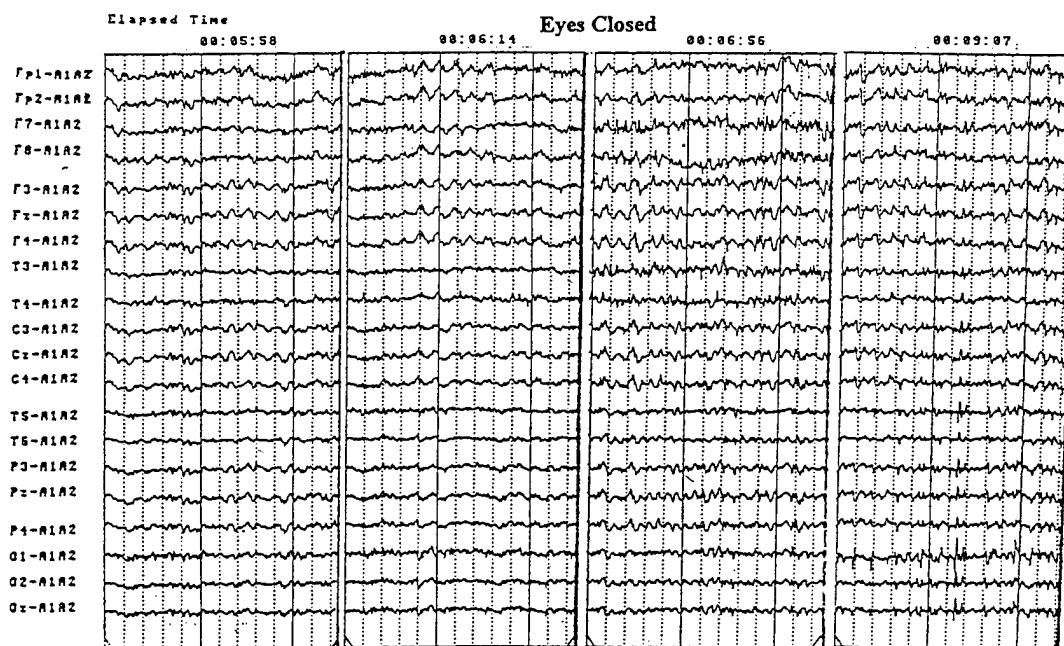
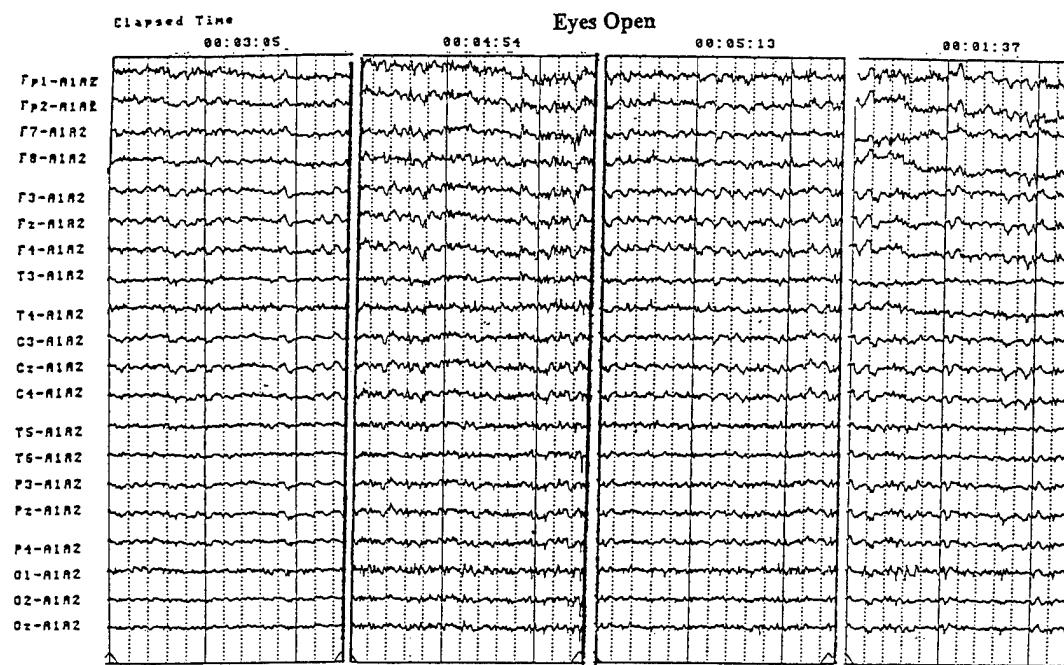


Figure A-39. The four artifact-free EEG epochs on which spectral analyses were conducted for pilot 10 in the laboratory.

**Helicopter**

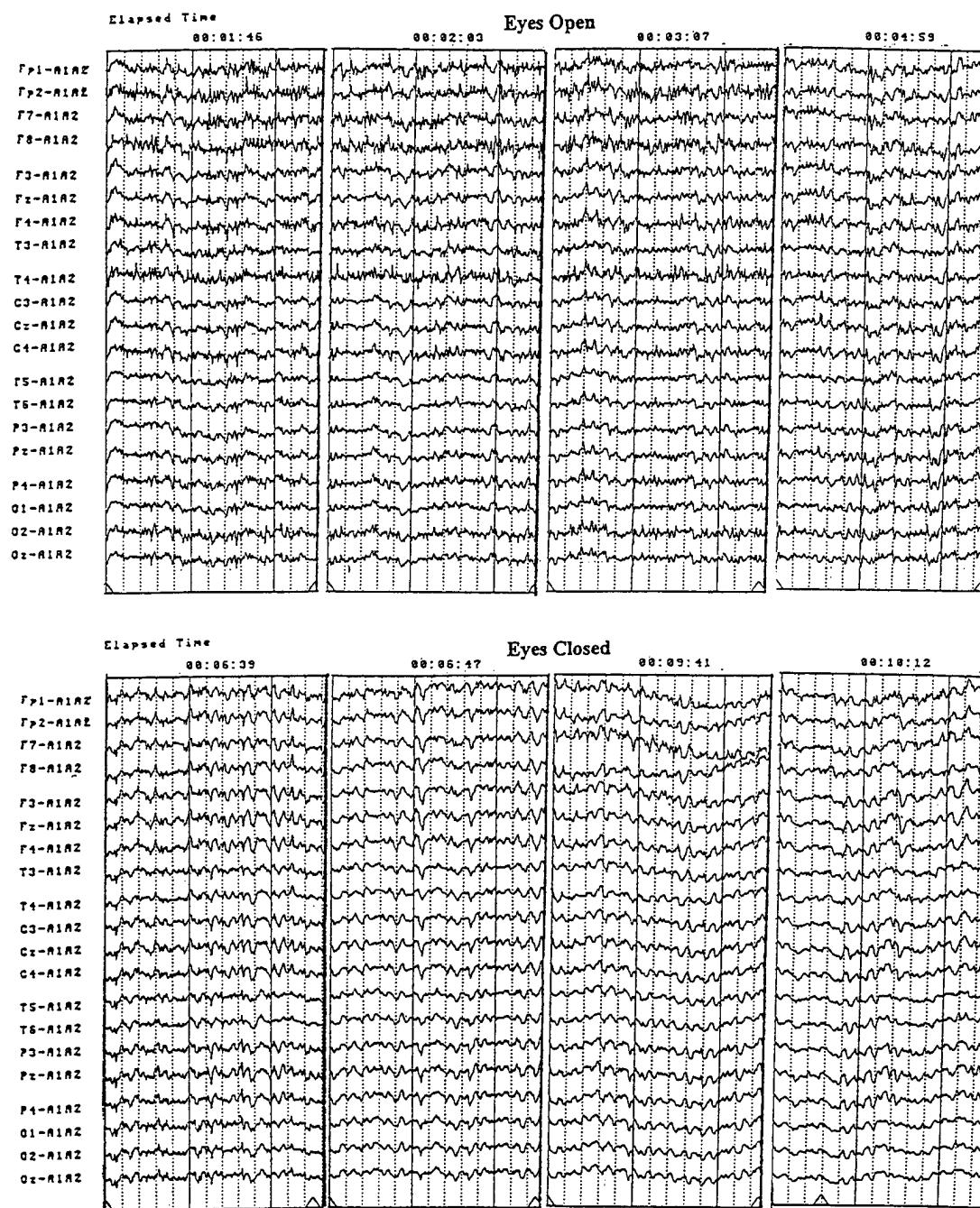


Figure A-40. The four artifact-free EEG epochs on which spectral analyses were conducted for pilot 10 in the helicopter.

Laboratory

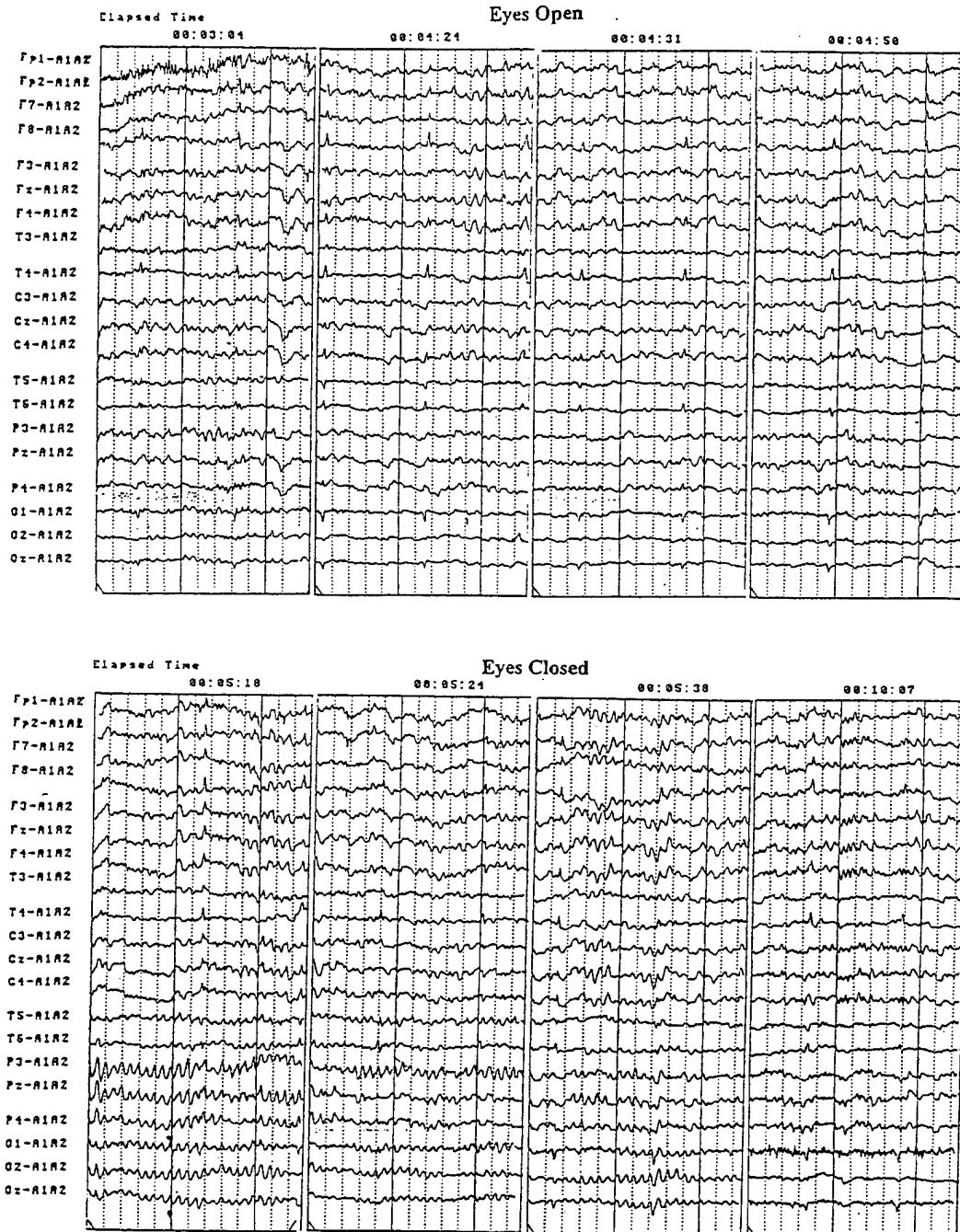


Figure A-41. The four artifact-free EEG epochs on which spectral analyses were conducted for non-pilot 1 in the laboratory.

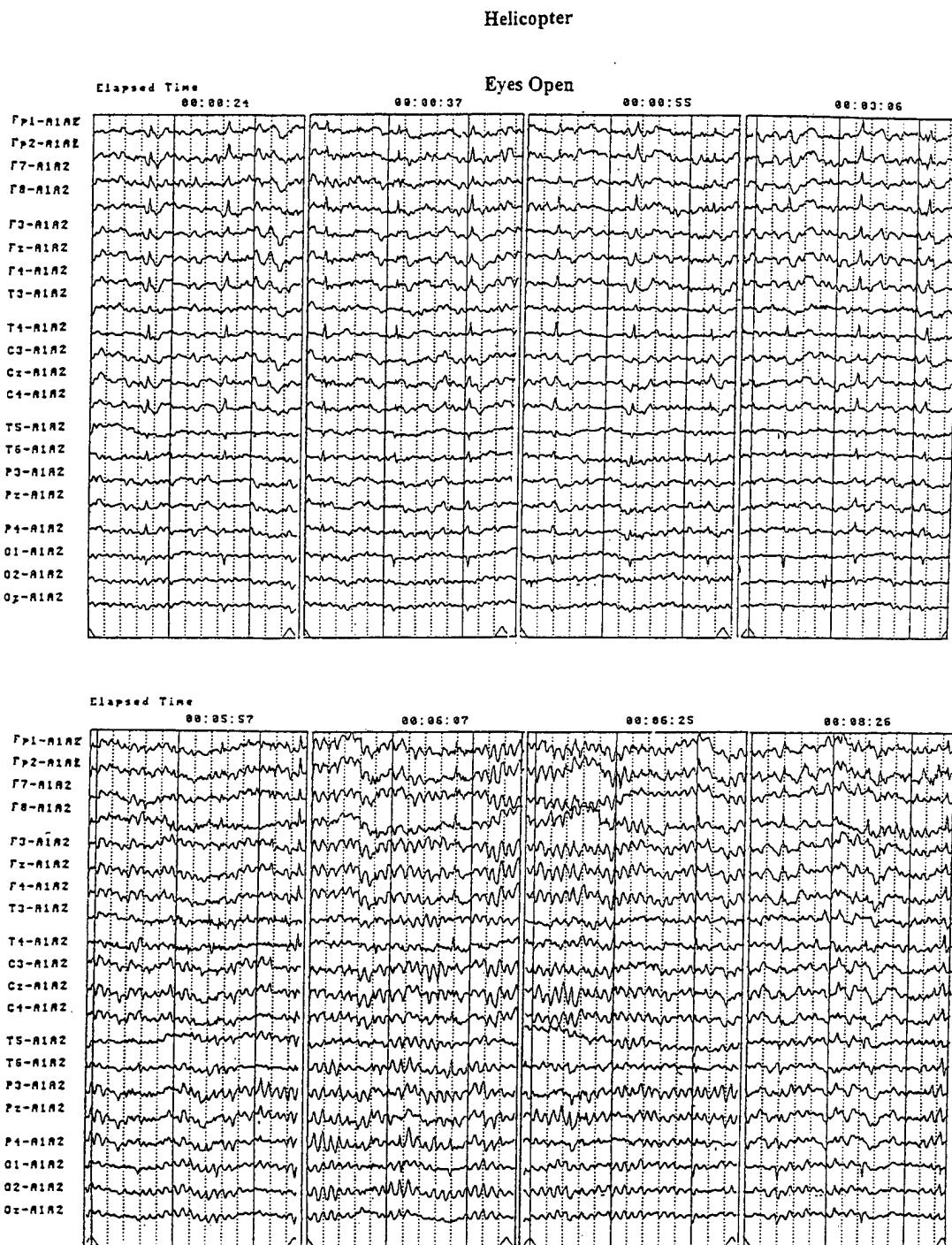


Figure A-42. The four artifact-free EEG epochs on which spectral analyses were conducted for non-pilot 1 in the helicopter.

Laboratory

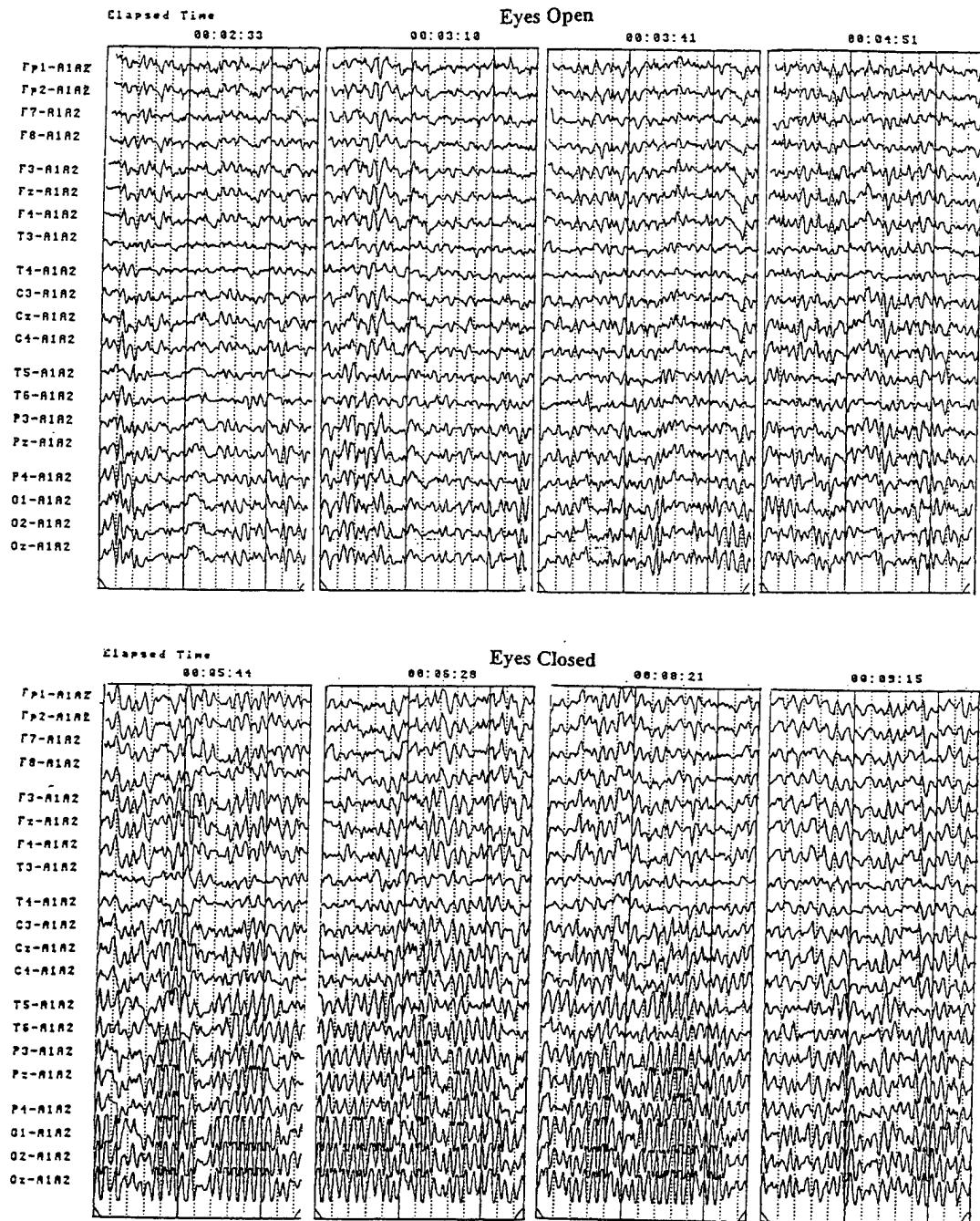


Figure A-43. The four artifact-free EEG epochs on which spectral analyses were conducted for non-pilot 2 in the laboratory.

**Helicopter**

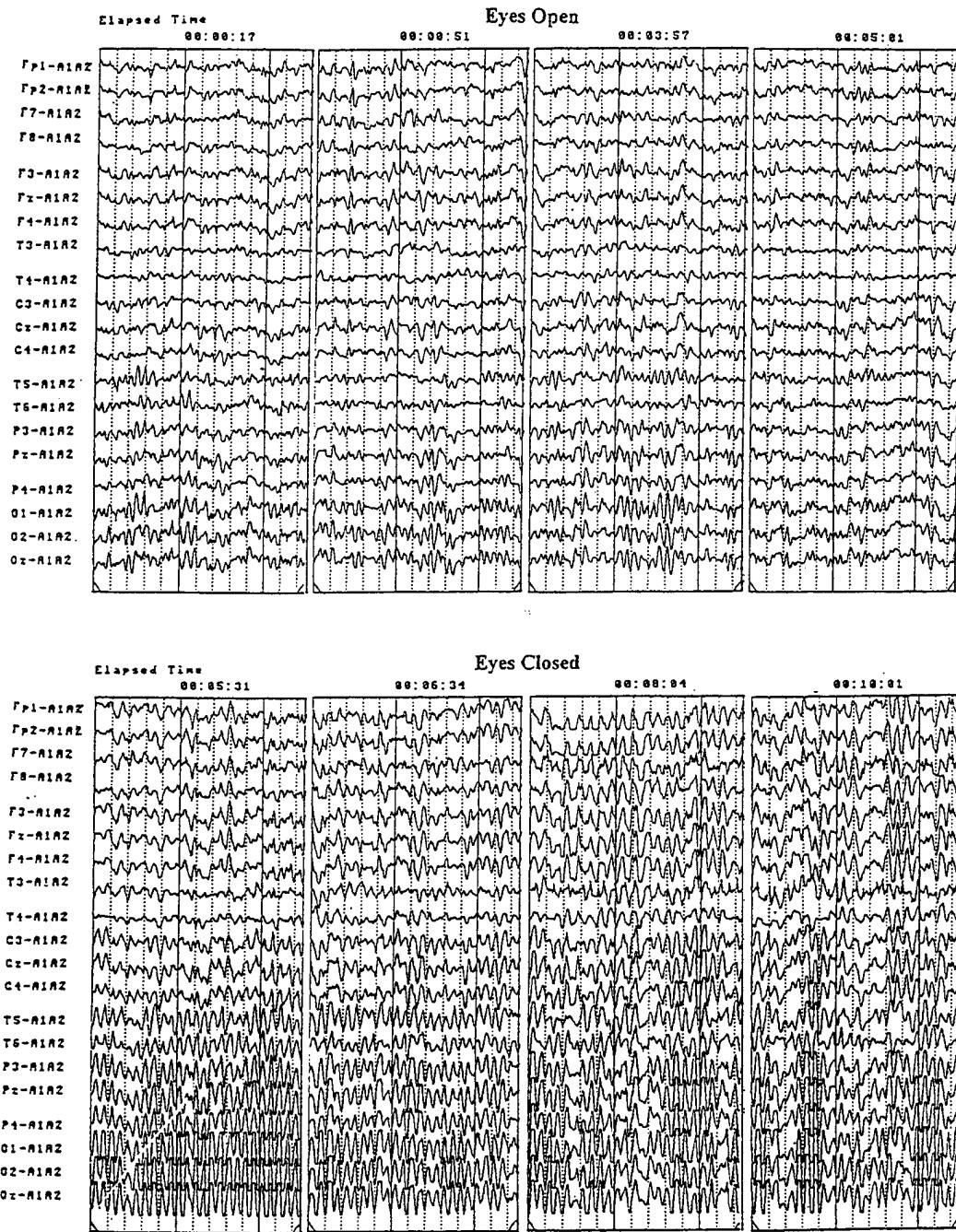


Figure A-44. The four artifact-free EEG epochs on which spectral analyses were conducted for non-pilot 2 in the helicopter.

Laboratory

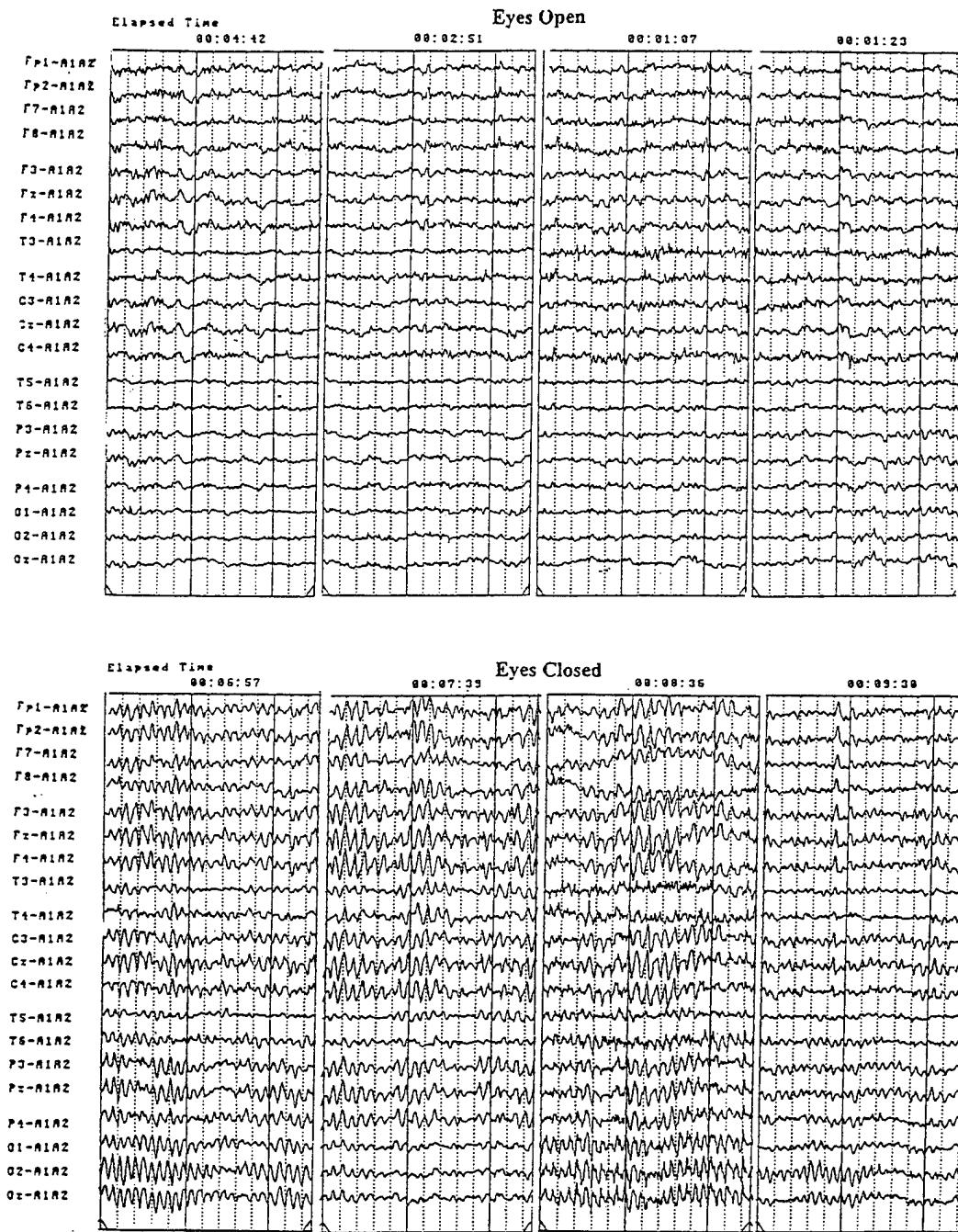


Figure A-45. The four artifact-free EEG epochs on which spectral analyses were conducted for non-pilot 3 in the laboratory.

**Helicopter**

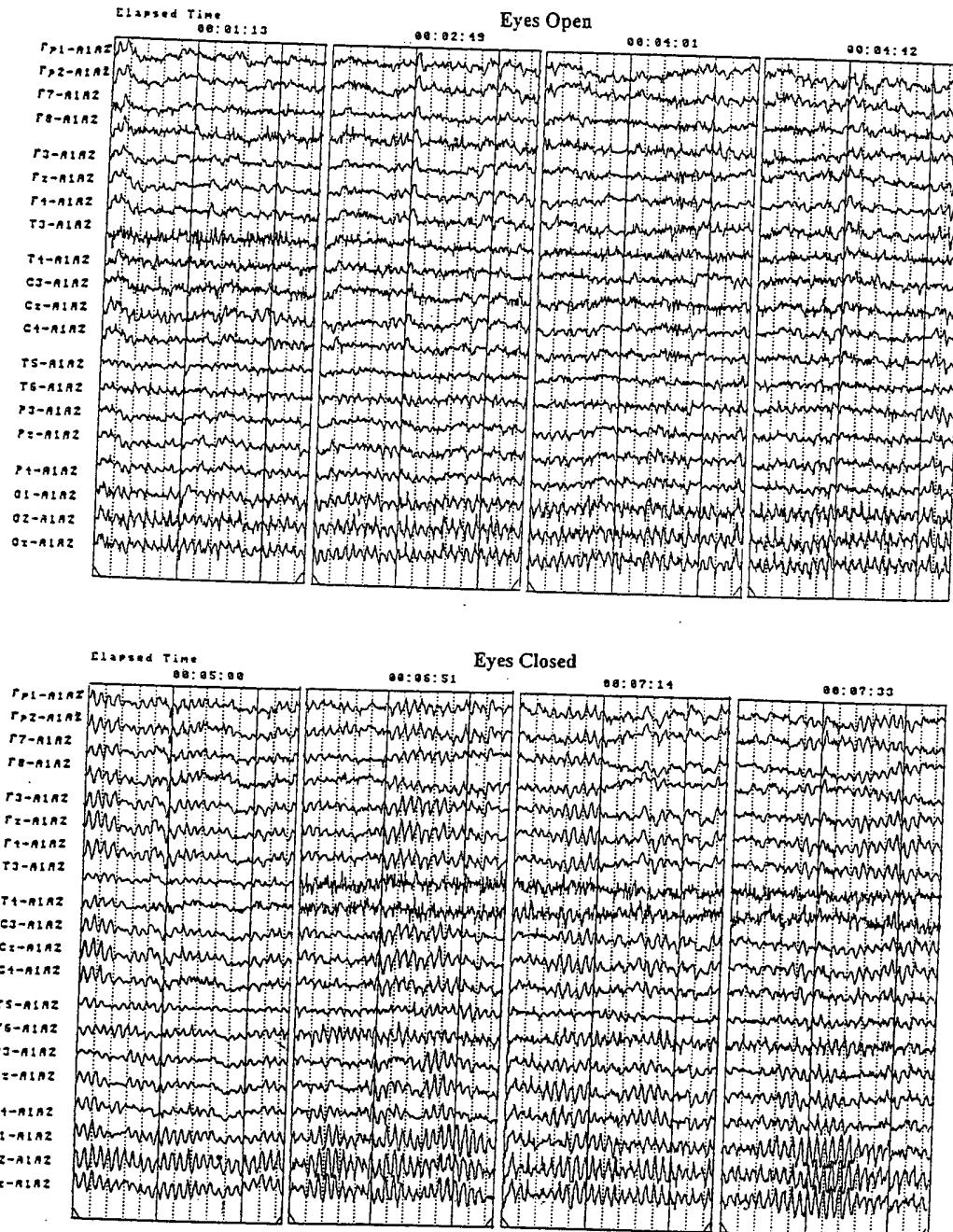


Figure A-46. The four artifact-free EEG epochs on which spectral analyses were conducted for non-pilot 3 in the helicopter.

Laboratory

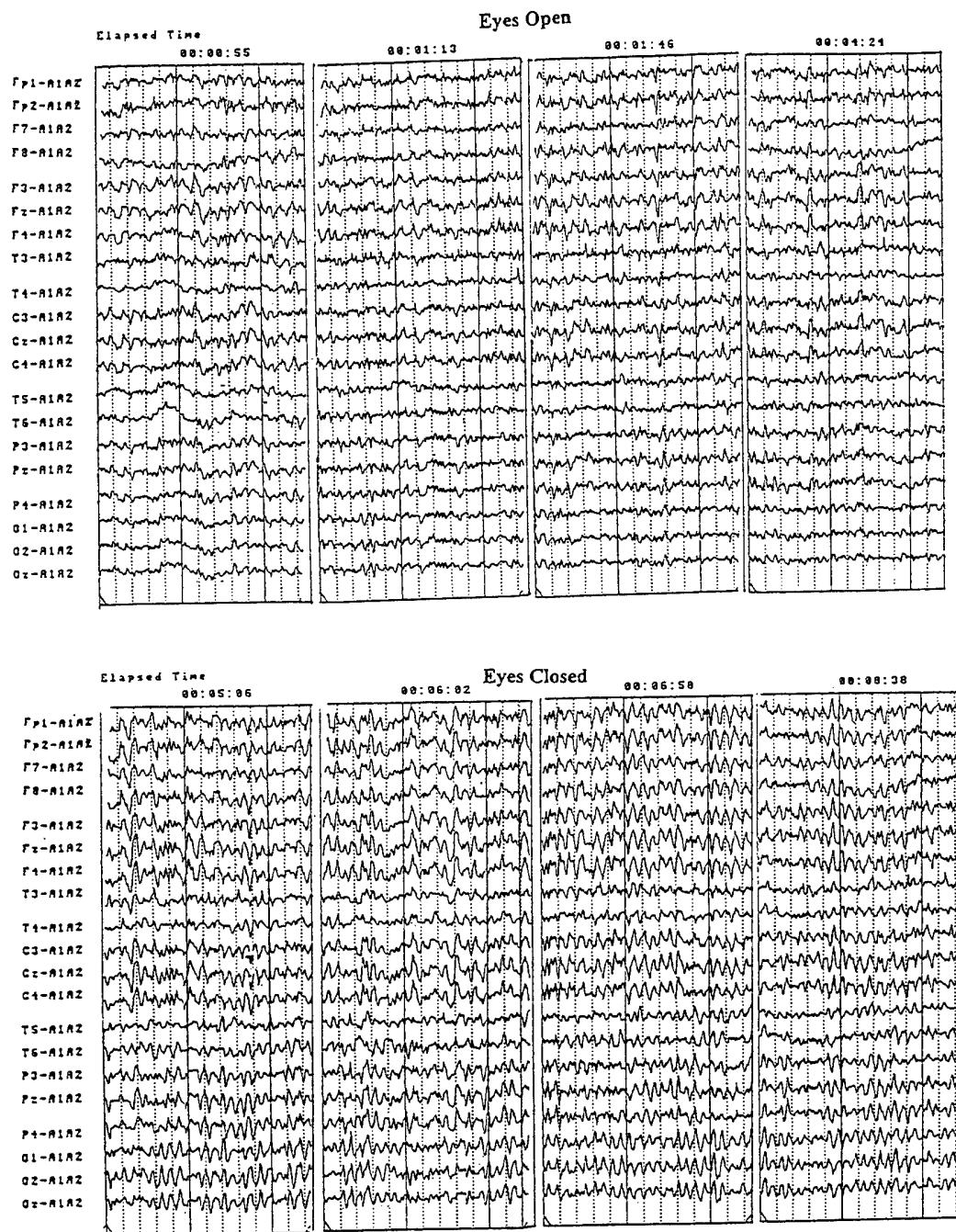


Figure A-47. The four artifact-free EEG epochs on which spectral analyses were conducted for non-pilot 4 in the laboratory.

Helicopter

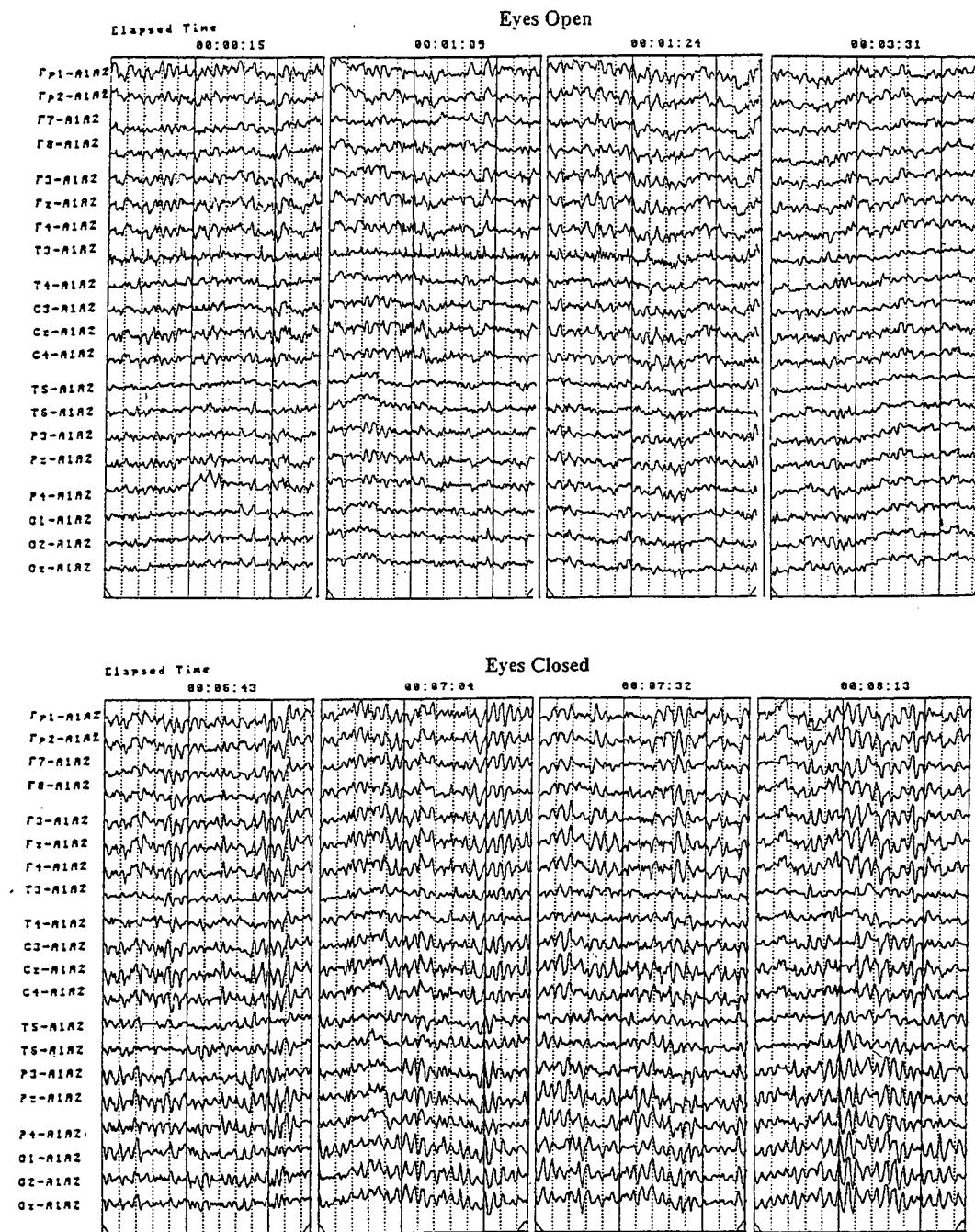


Figure A-48. The four artifact-free EEG epochs on which spectral analyses were conducted for non-pilot 4 in the helicopter.

Laboratory

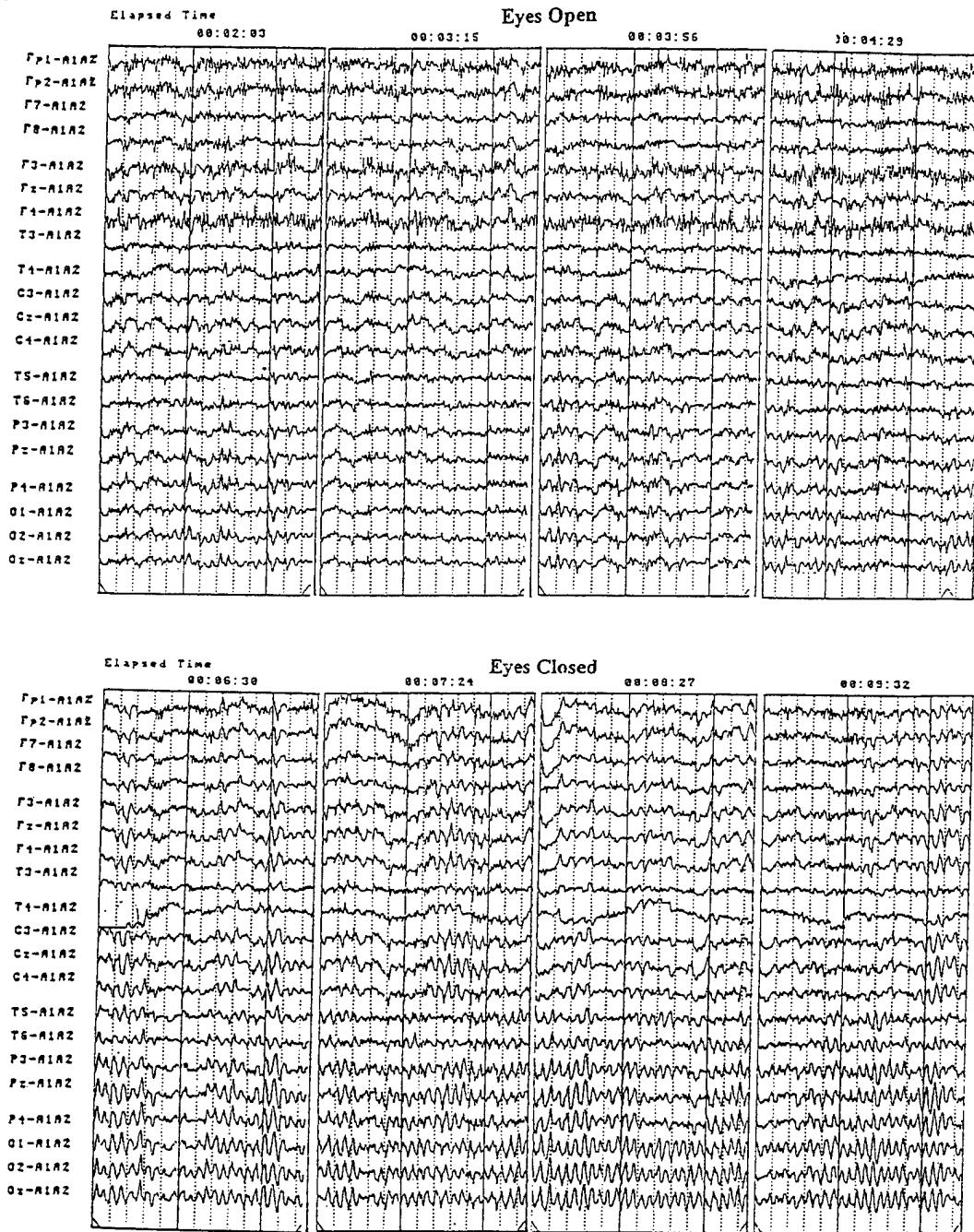


Figure A-49. The four artifact-free EEG epochs on which spectral analyses were conducted for non-pilot 5 in the laboratory.

Helicopter

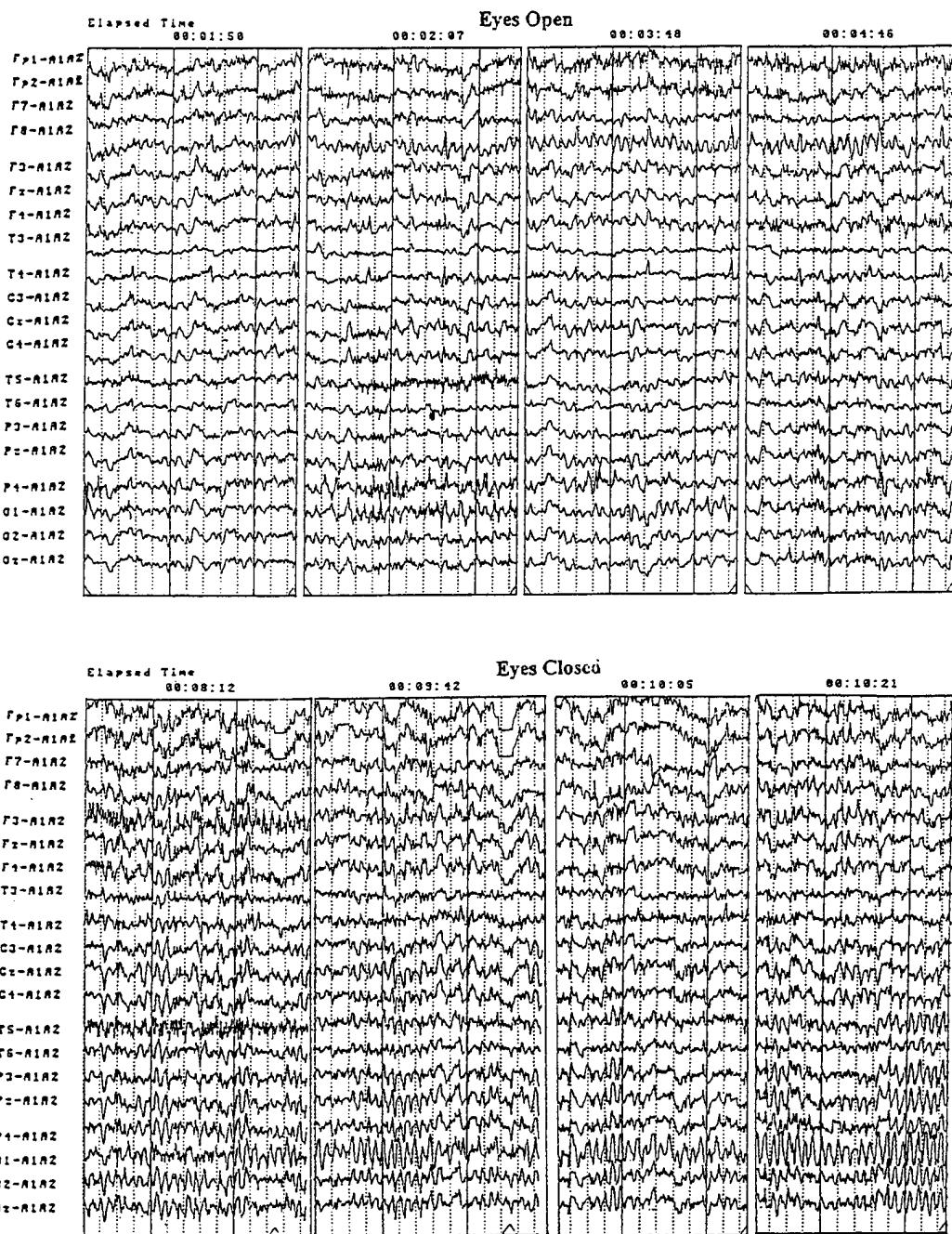


Figure A-50. The four artifact-free EEG epochs on which spectral analyses were conducted for non-pilot 5 in the helicopter.

**Laboratory**

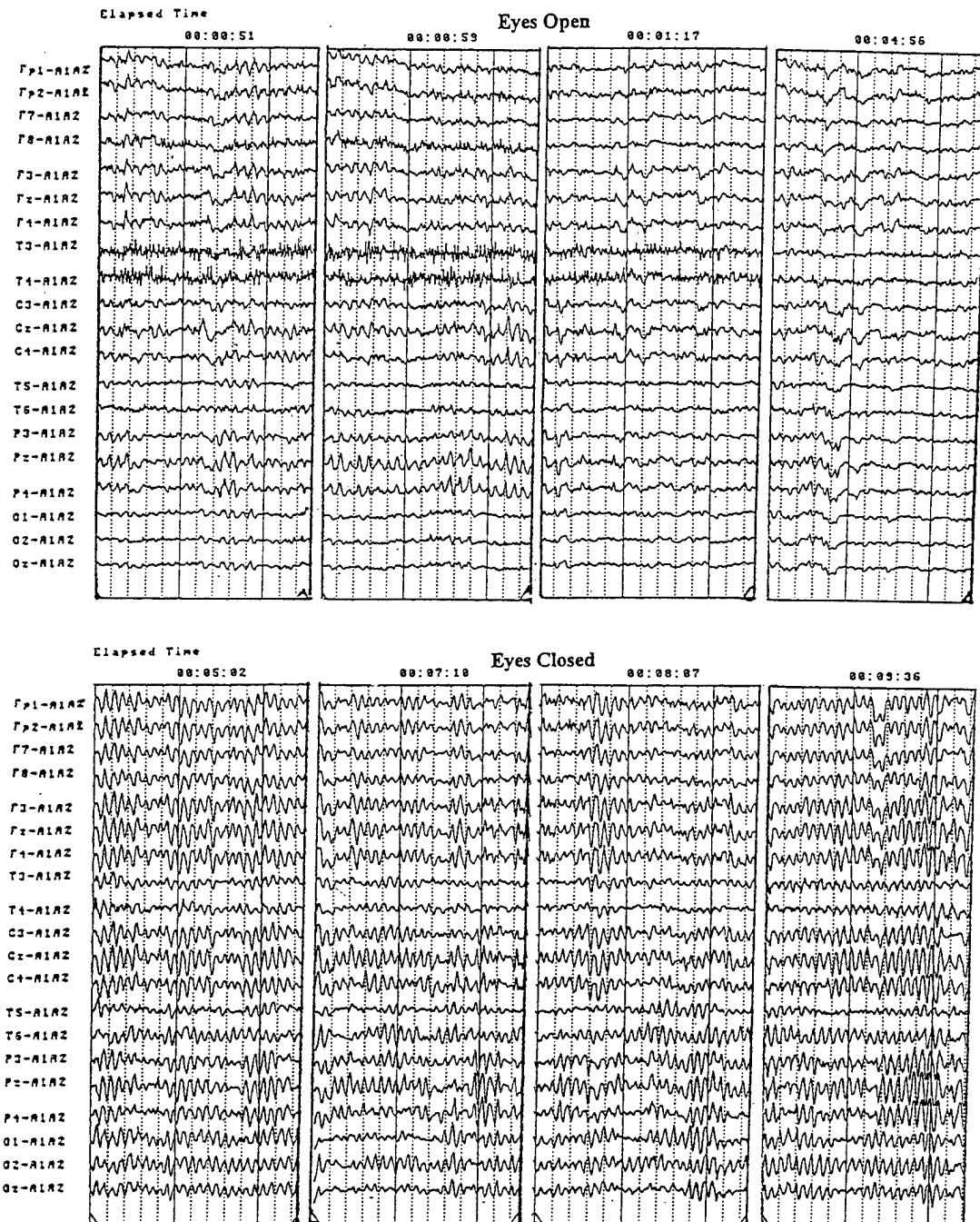


Figure A-51. The four artifact-free EEG epochs on which spectral analyses were conducted for non-pilot 6 in the laboratory.

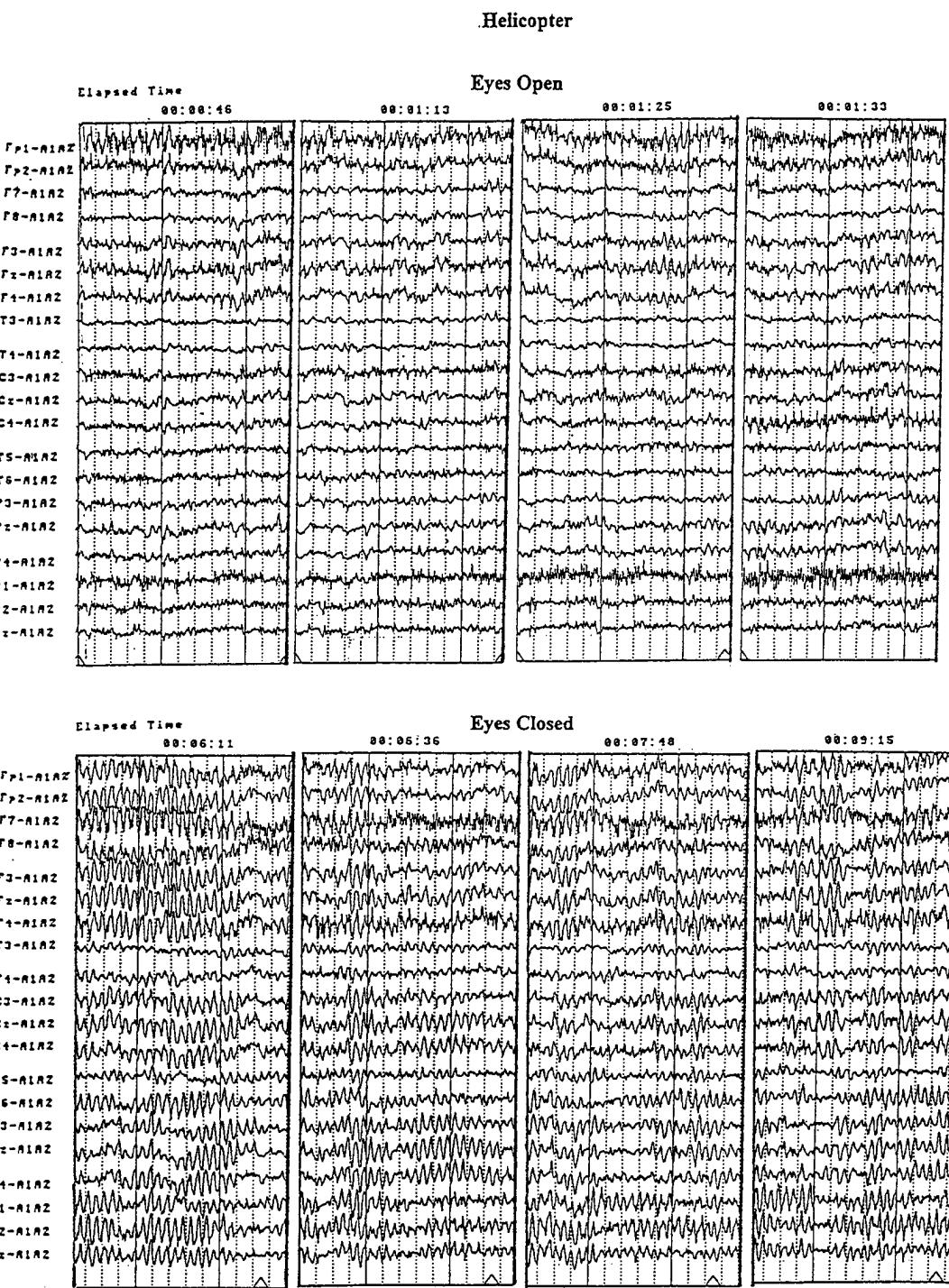


Figure A-52. The four artifact-free EEG epochs on which spectral analyses were conducted for non-pilot 6 in the helicopter.

Laboratory

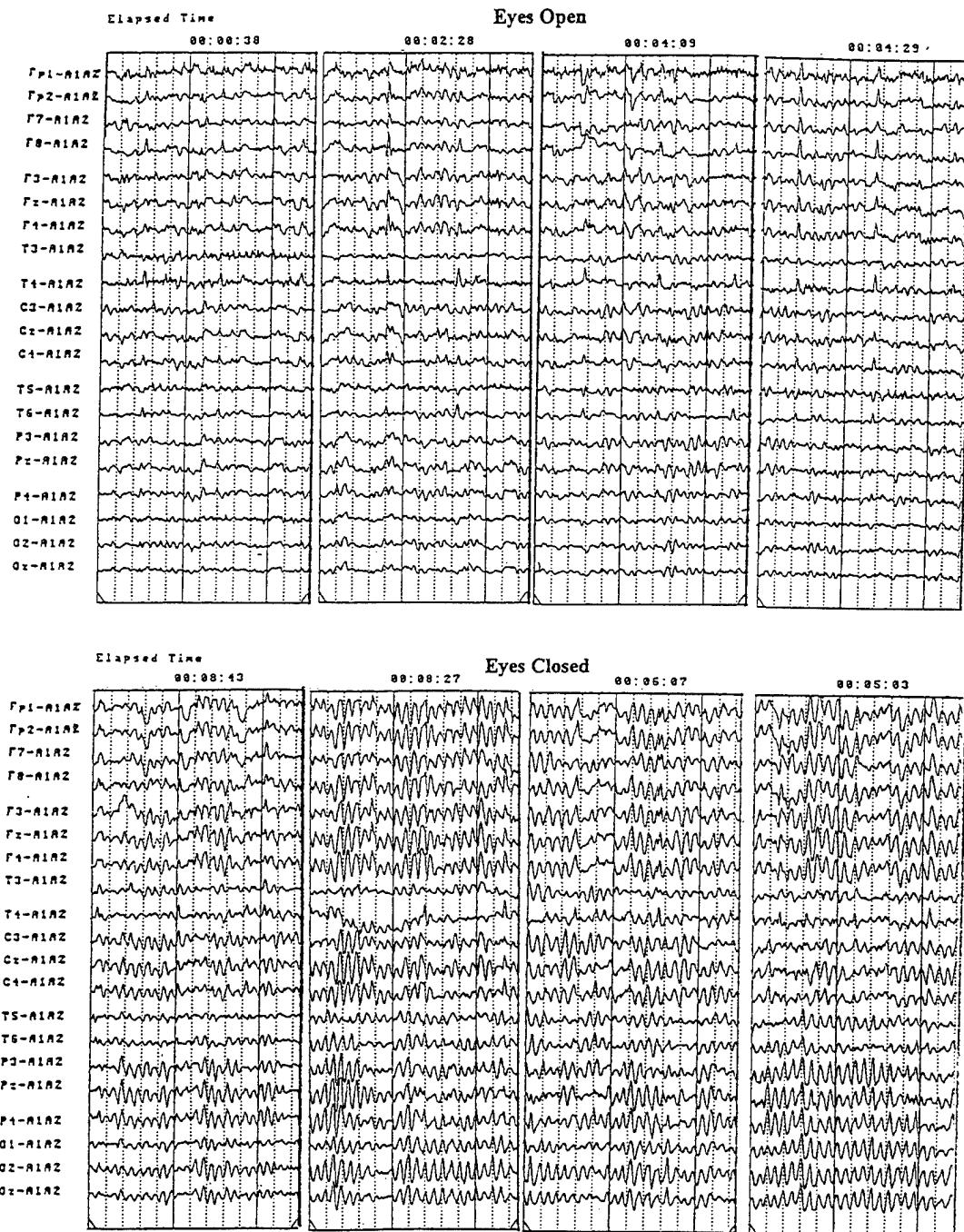


Figure A-53: The four artifact-free EEG epochs on which spectral analyses were conducted for non-pilot 7 in the laboratory.

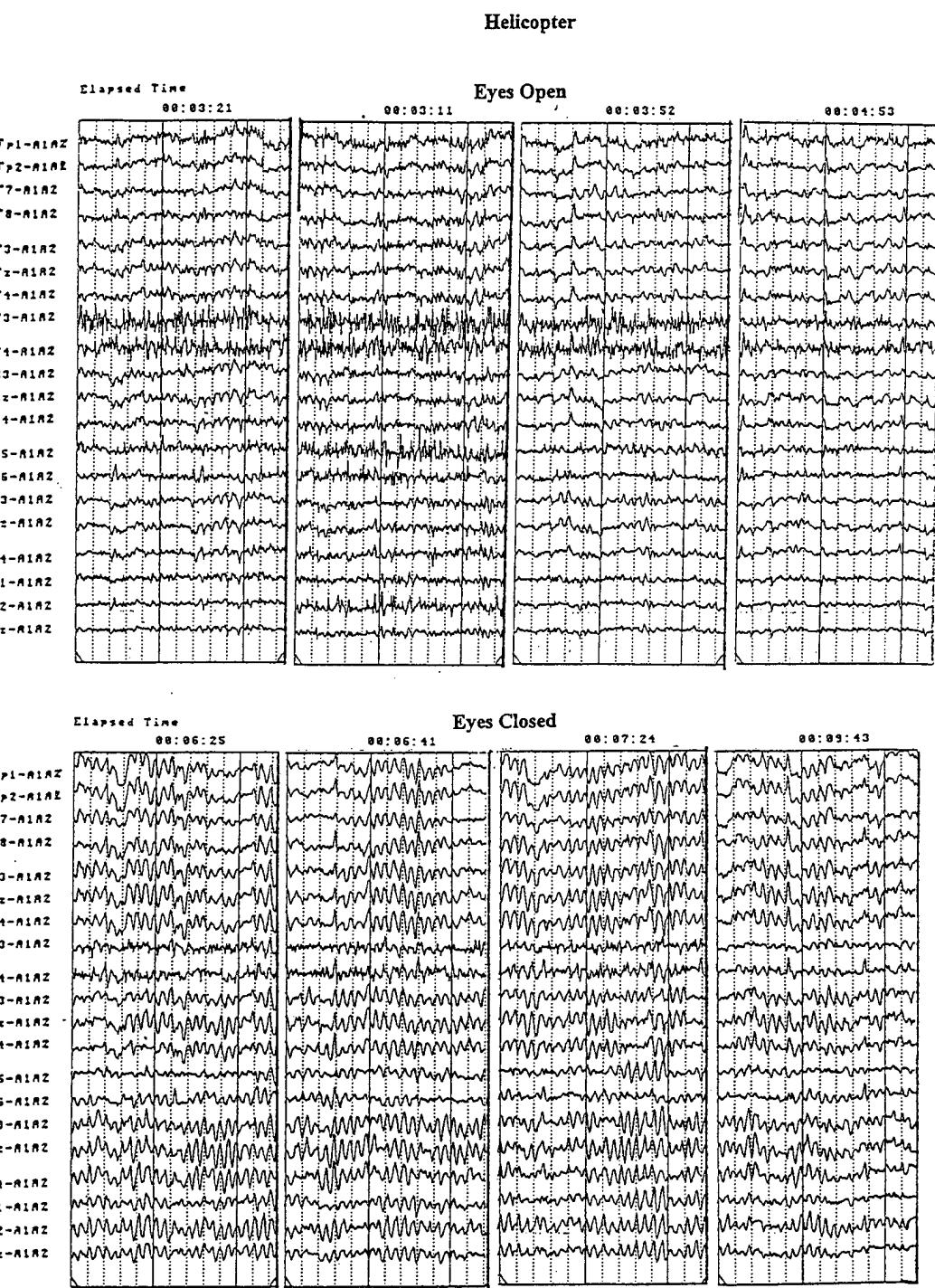


Figure A-54. The four artifact-free EEG epochs on which spectral analyses were conducted for non-pilot 7 in the helicopter.

## Laboratory

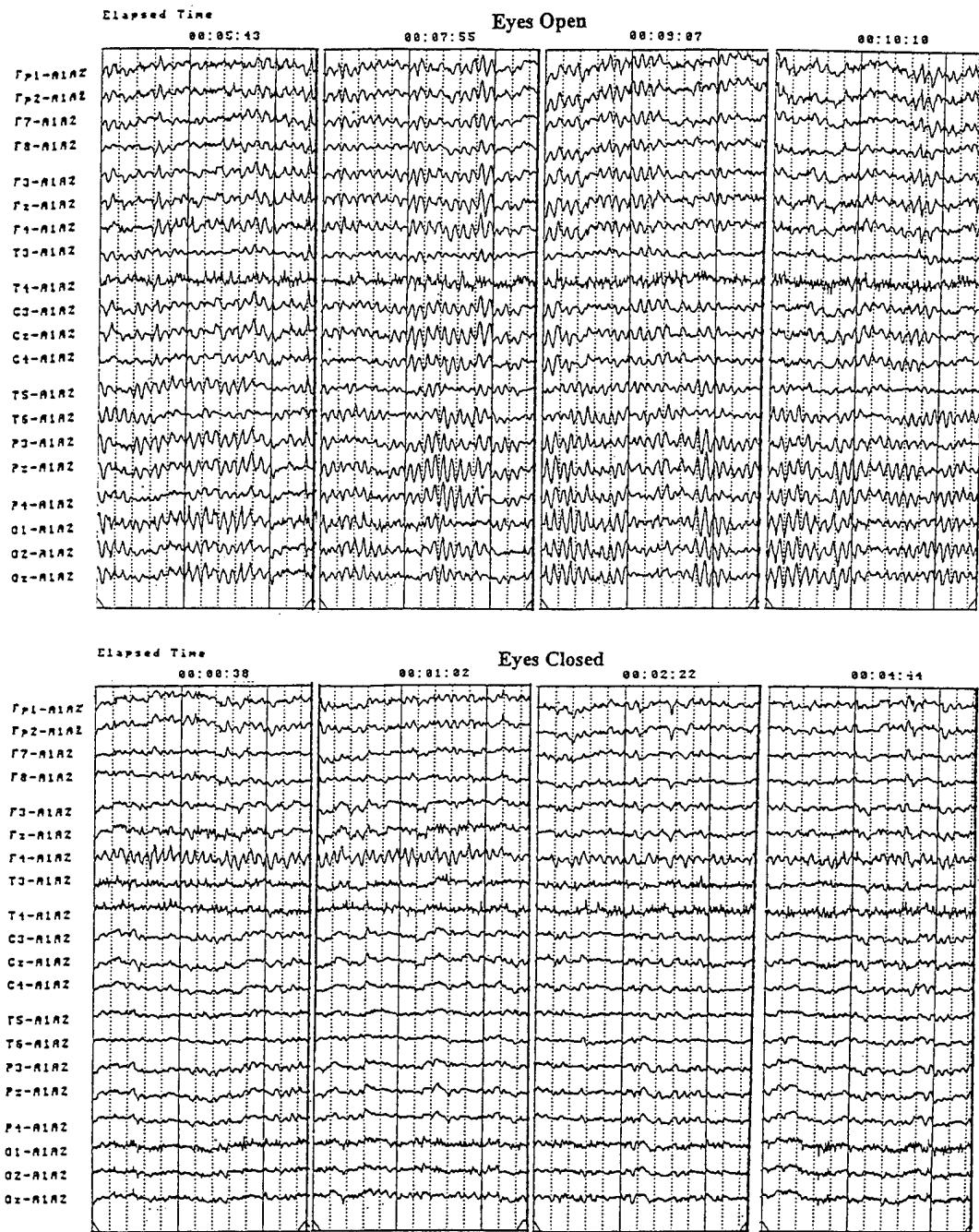


Figure A-55. The four artifact-free EEG epochs on which spectral analyses were conducted for non-pilot 8 in the laboratory.

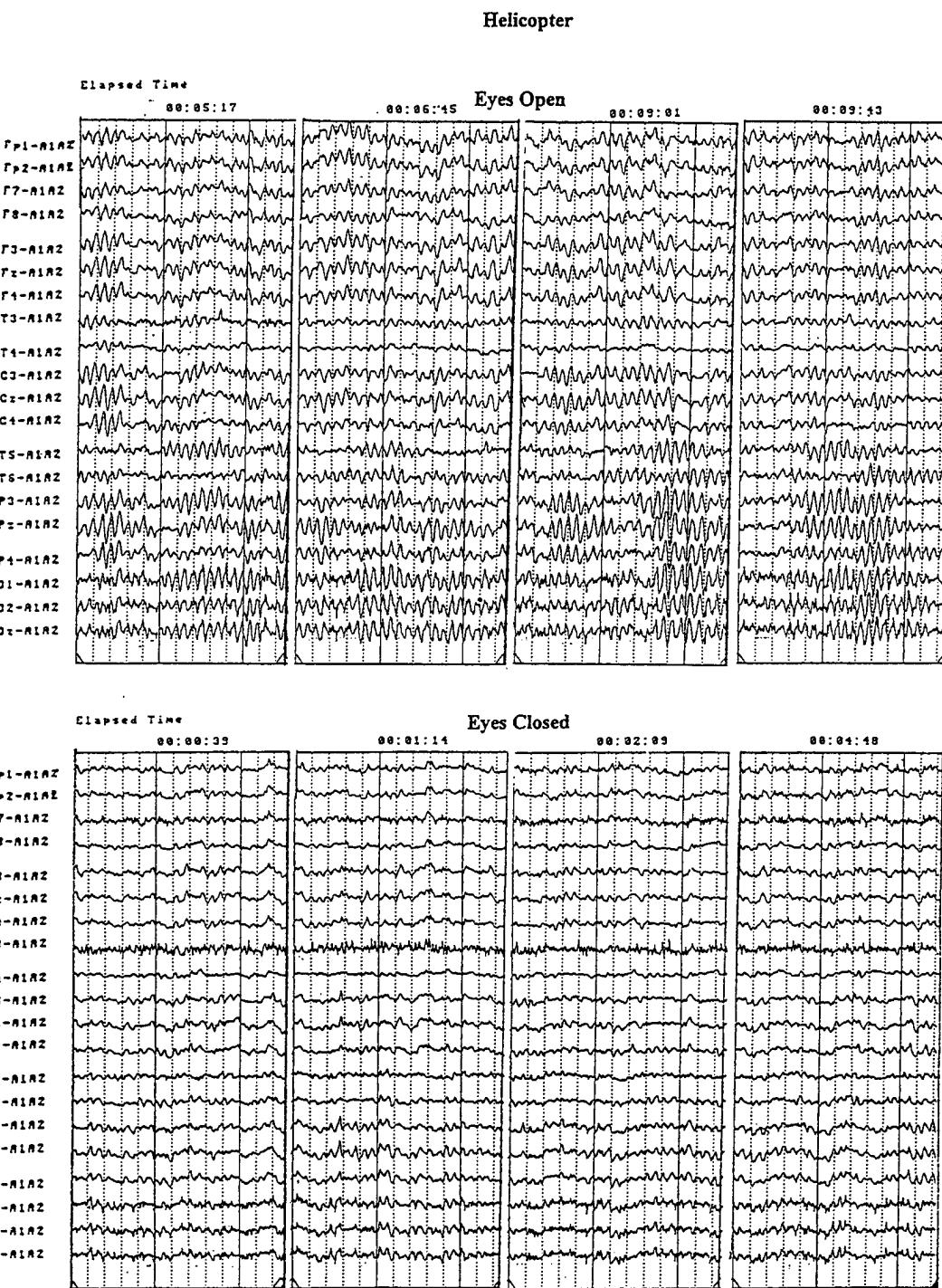


Figure A-56. The four artifact-free EEG epochs on which spectral analyses were conducted for non-pilot 8 in the helicopter.

Laboratory

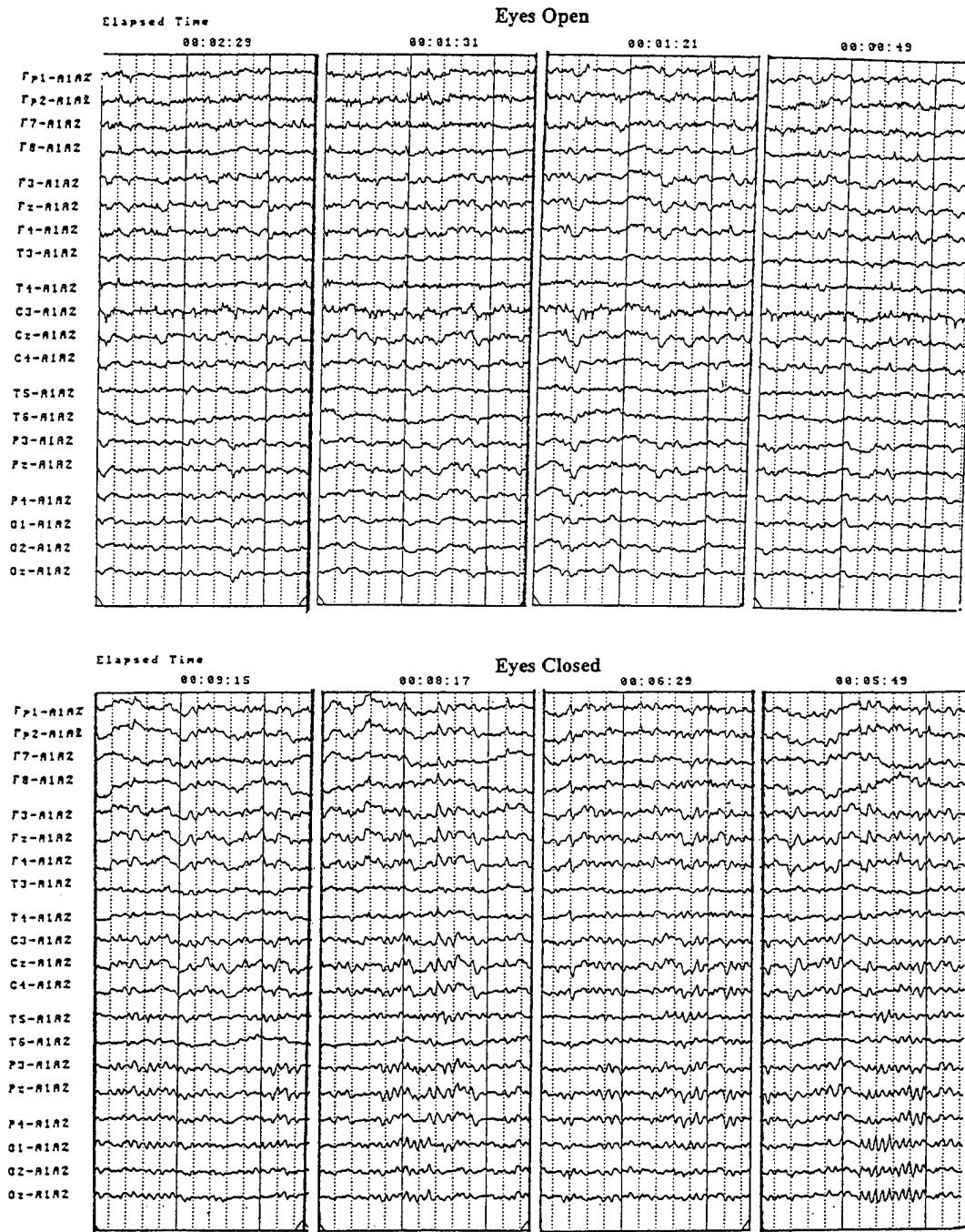


Figure A-57. The four artifact-free EEG epochs on which spectral analyses were conducted for non-pilot 9 in the laboratory.

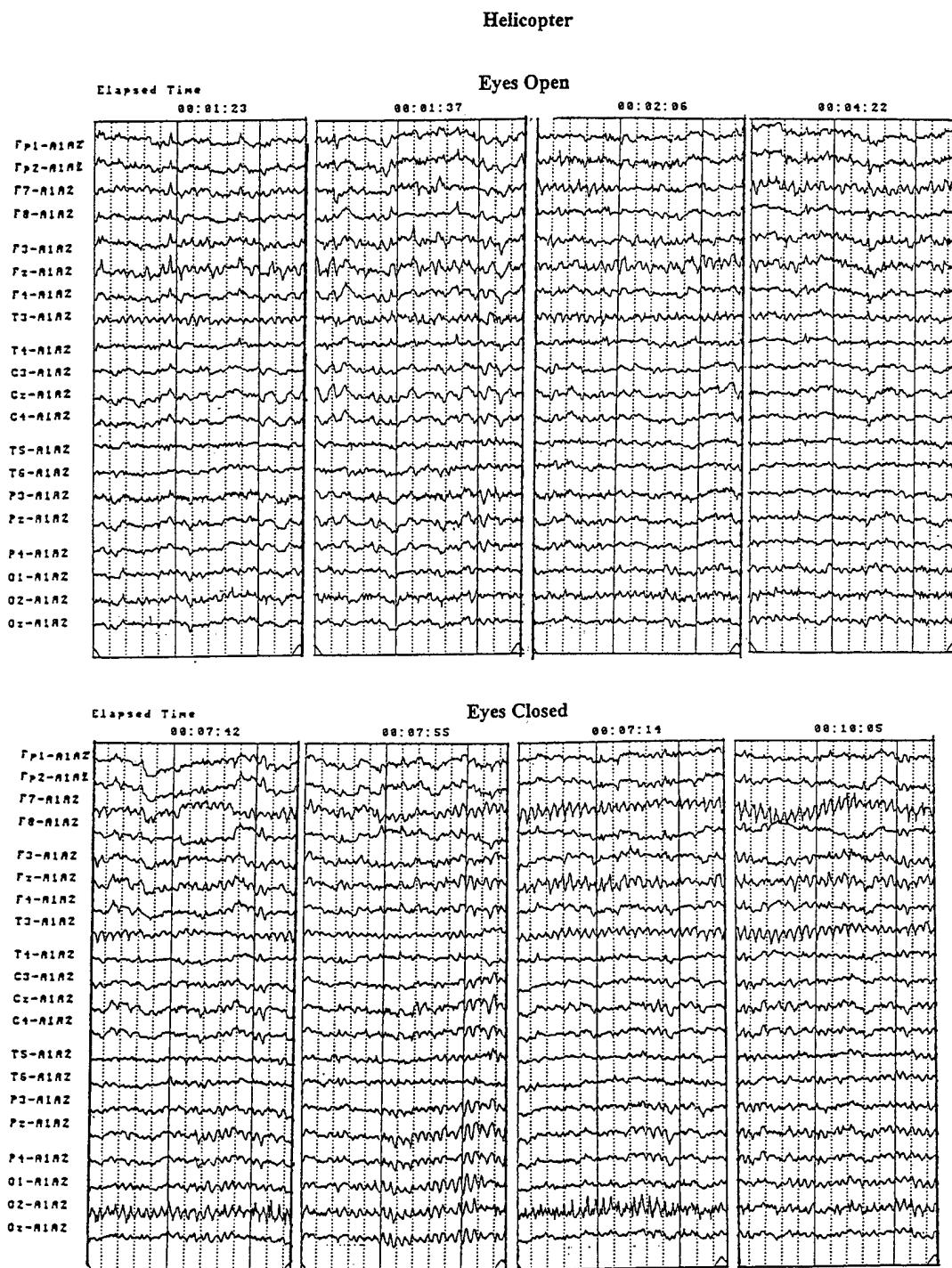


Figure A-58. The four artifact-free EEG epochs on which spectral analyses were conducted for non-pilot 9 in the helicopter.

**Laboratory**

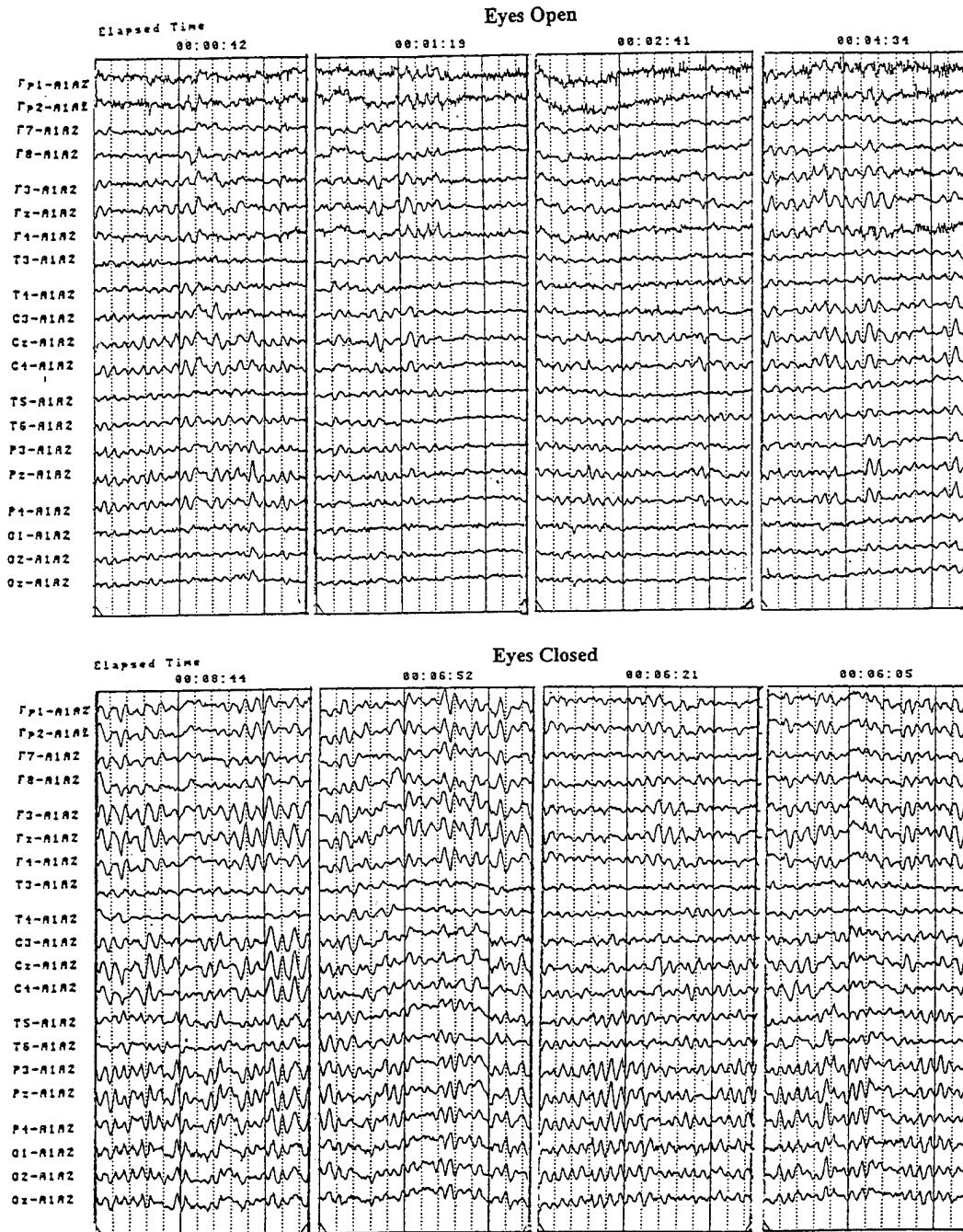


Figure A-59. The four artifact-free EEG epochs on which spectral analyses were conducted for non-pilot 10 in the laboratory.

**Helicopter**

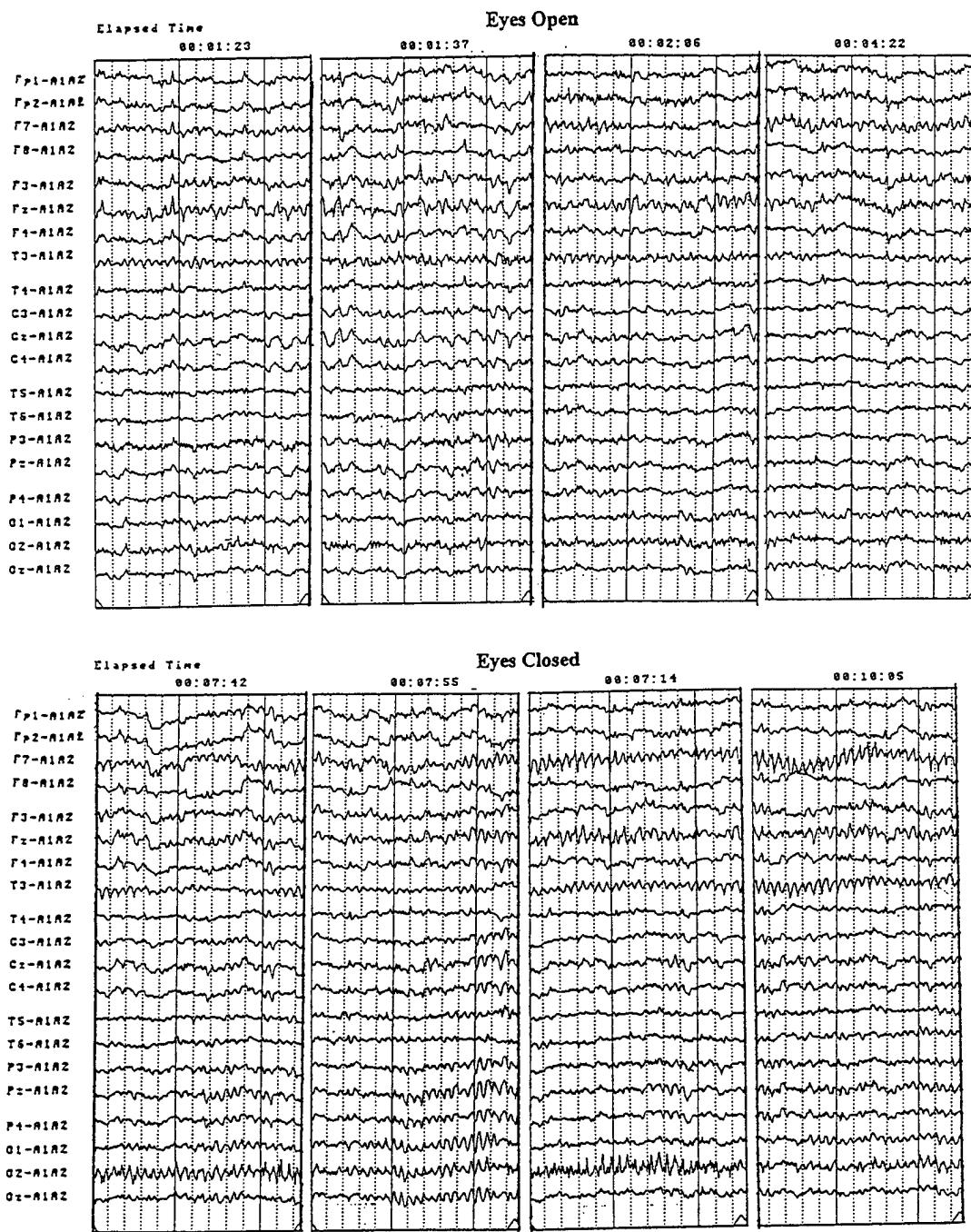
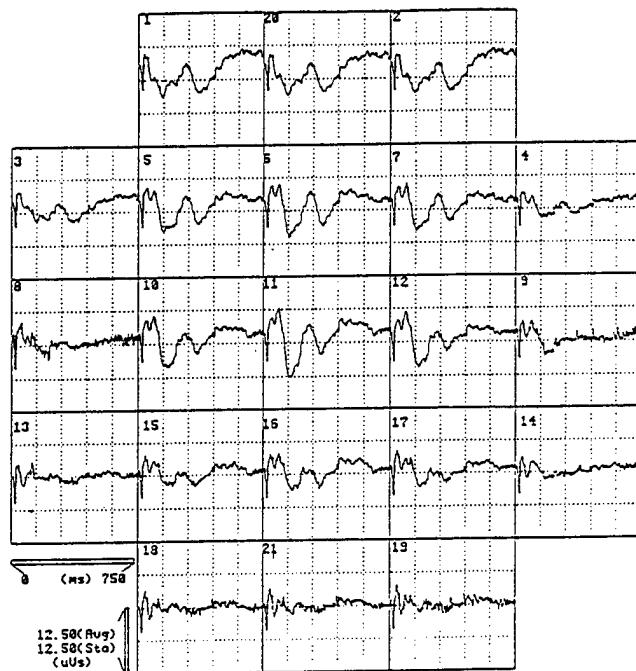


Figure A-60. The four artifact-free EEG epochs on which spectral analyses were conducted for non-pilot 10 in the helicopter.

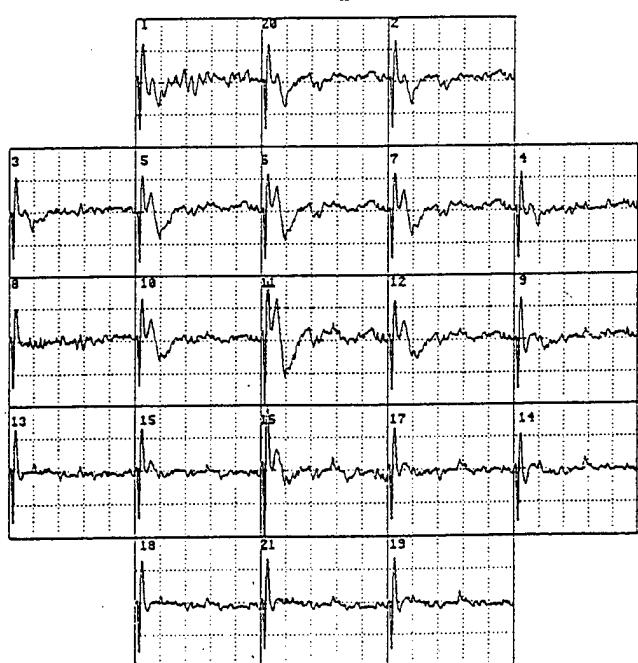
Appendix B.

Part 1. Examples of evoked potentials collected from each participant.

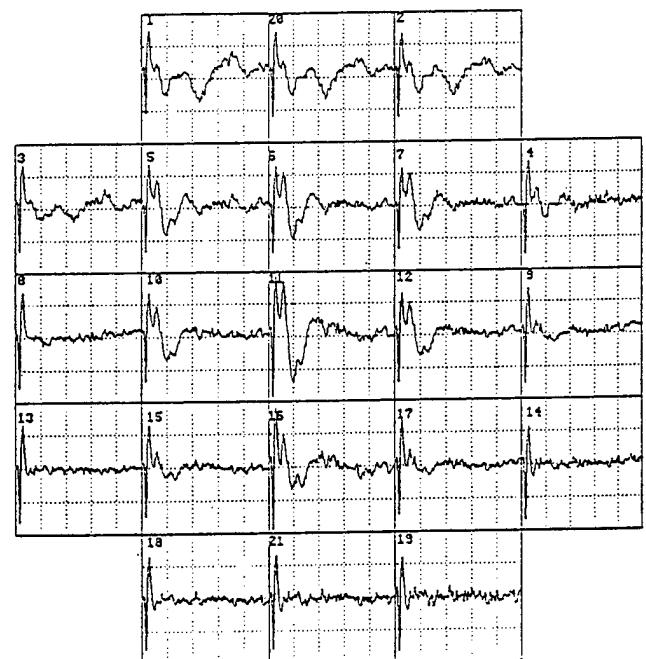
**In Laboratory**



**In Helicopter #1**

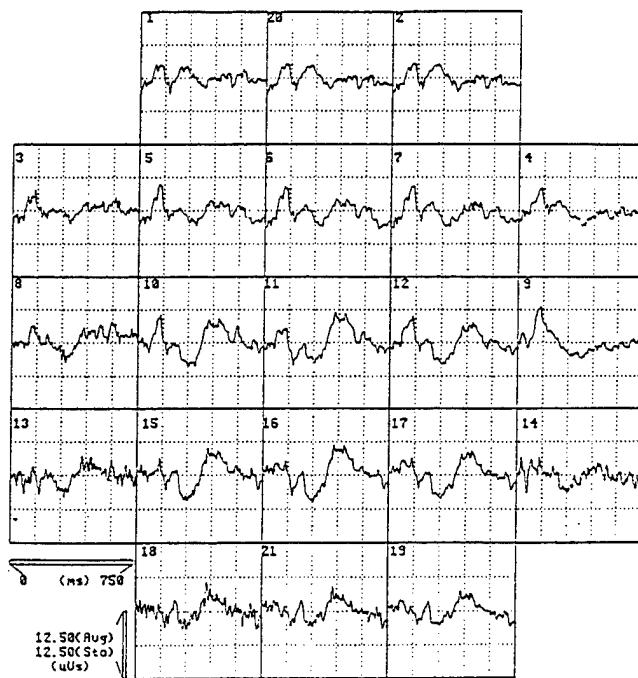


**In Helicopter #2**

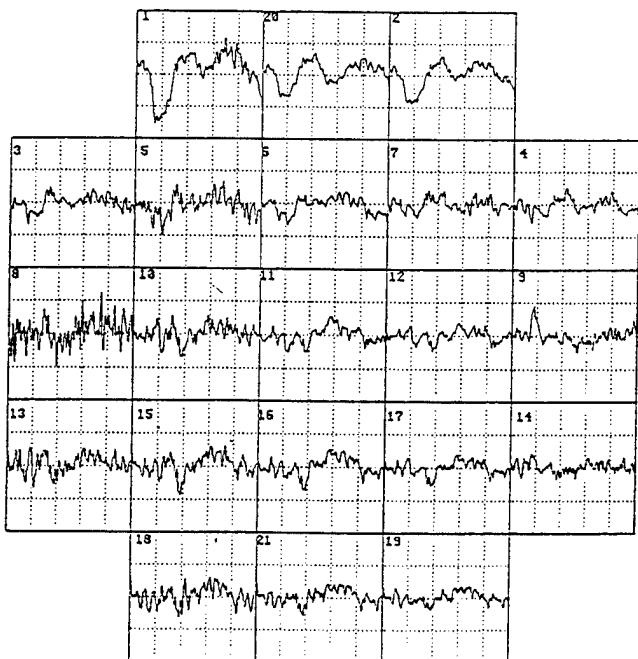


**Figure B-1.** P-300 waveforms collected from pilot 1 in the laboratory and two sets collected in the helicopter.

### In Laboratory



### In Helicopter #1



### In Helicopter #2

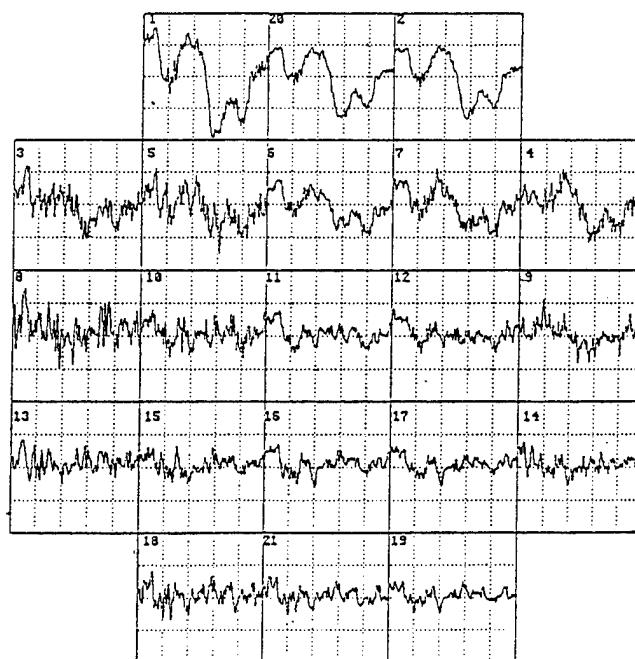
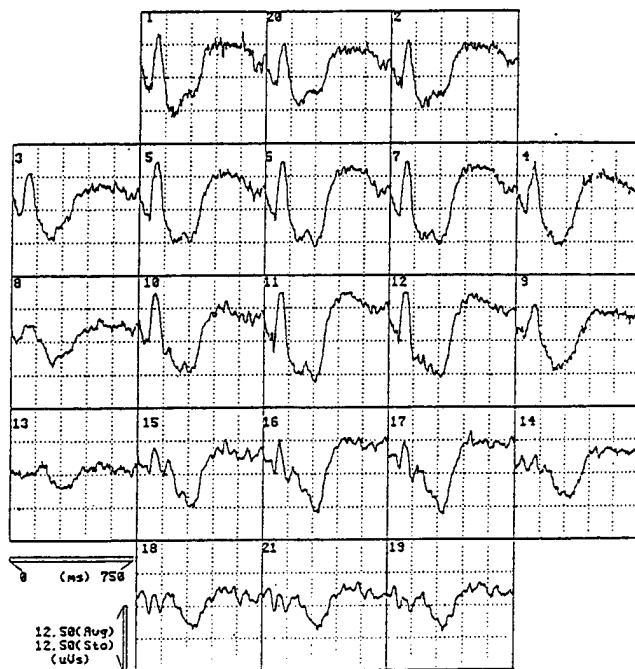
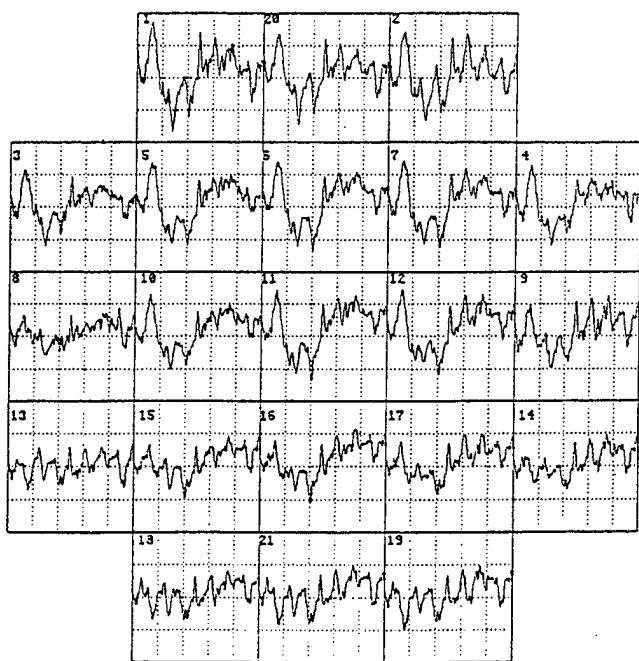


Figure B-2. P-300 waveforms collected from pilot 2 in the laboratory and two sets collected in the helicopter.

### In Laboratory



### In Helicopter #1



### In Helicopter #2

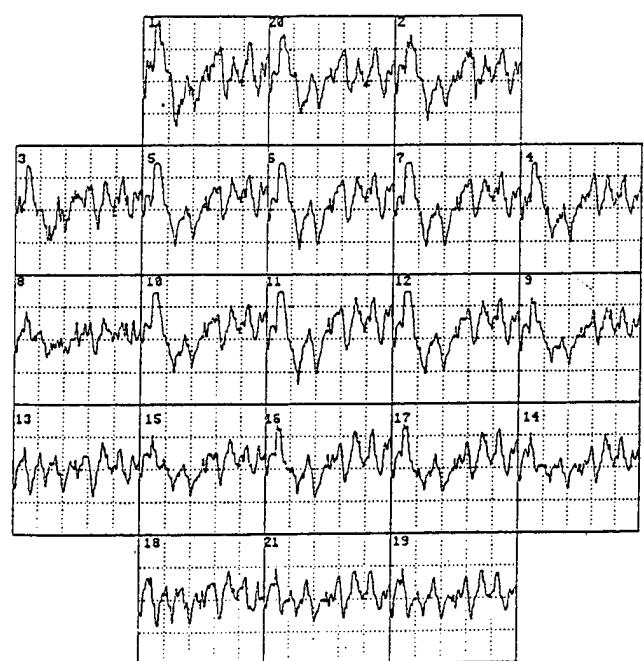
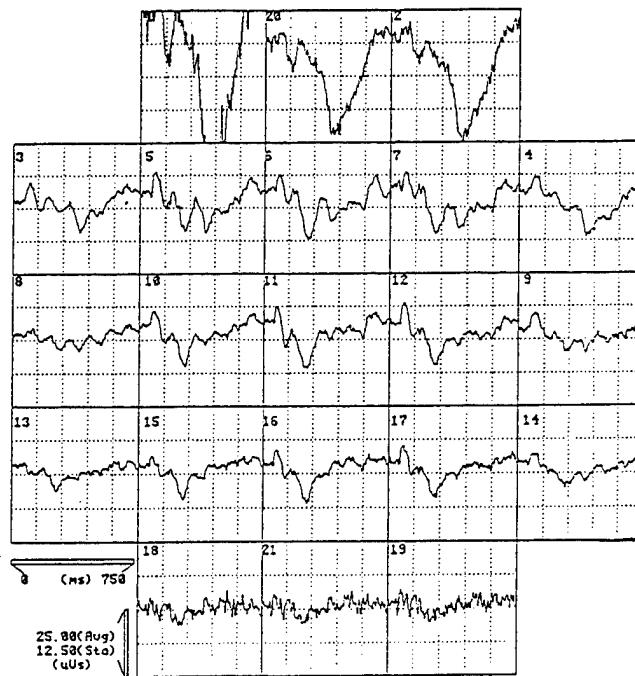
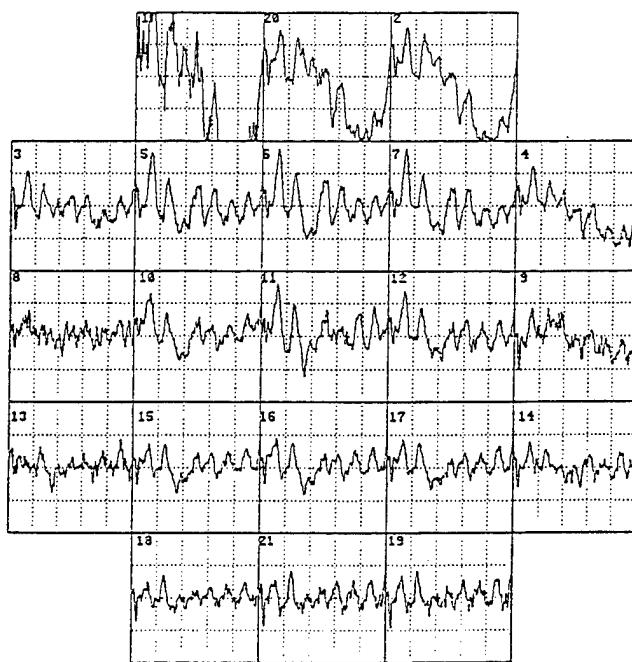


Figure B-3. P-300 waveforms collected from pilot 3 in the laboratory and two sets collected in the helicopter.

### In Laboratory



### In Helicopter #1



### In Helicopter #2

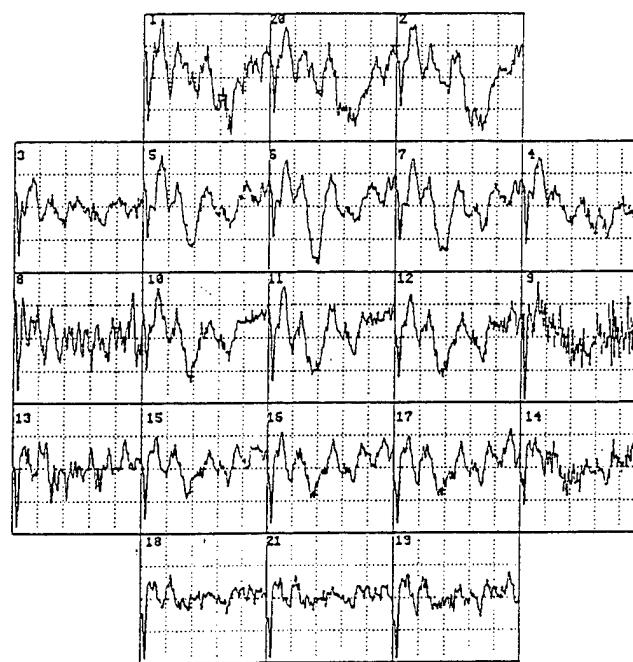
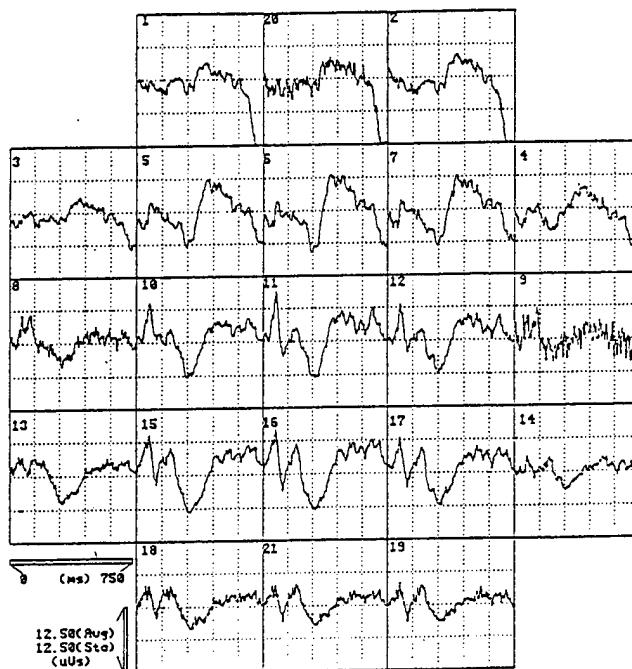
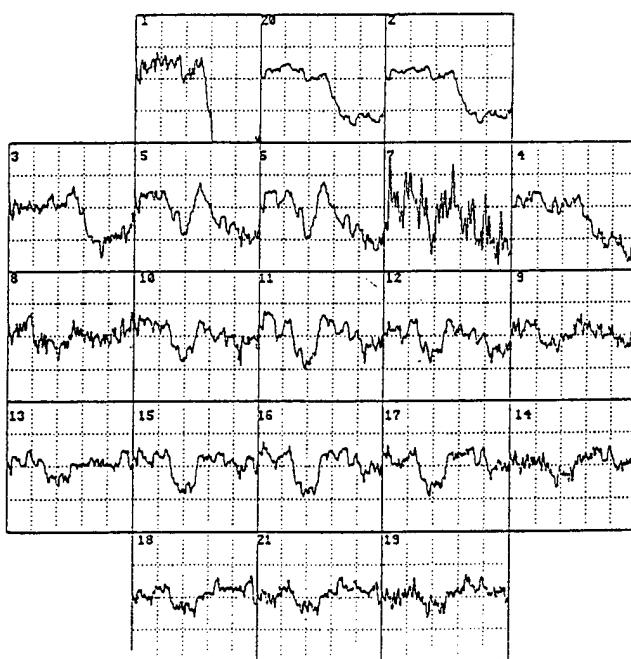


Figure B-4. P-300 waveforms collected from pilot 4 in the laboratory and two sets collected in the helicopter.

### In Laboratory



### In Helicopter #1



### In Helicopter #2

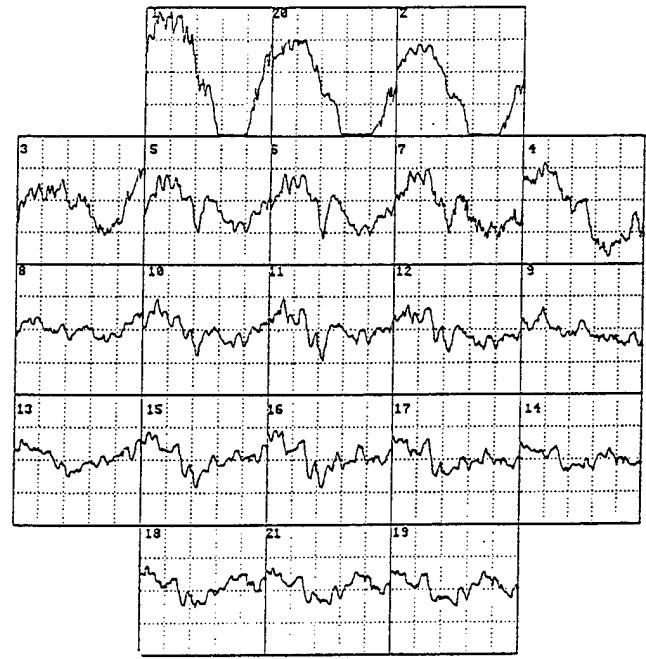
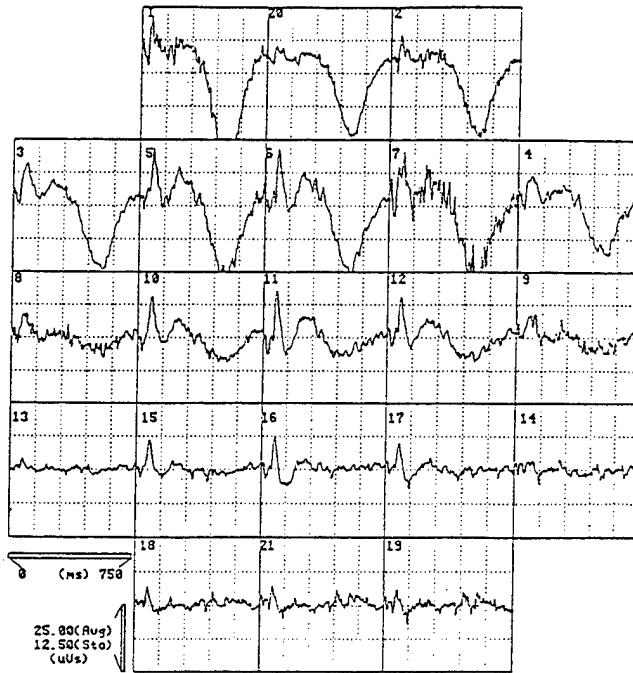
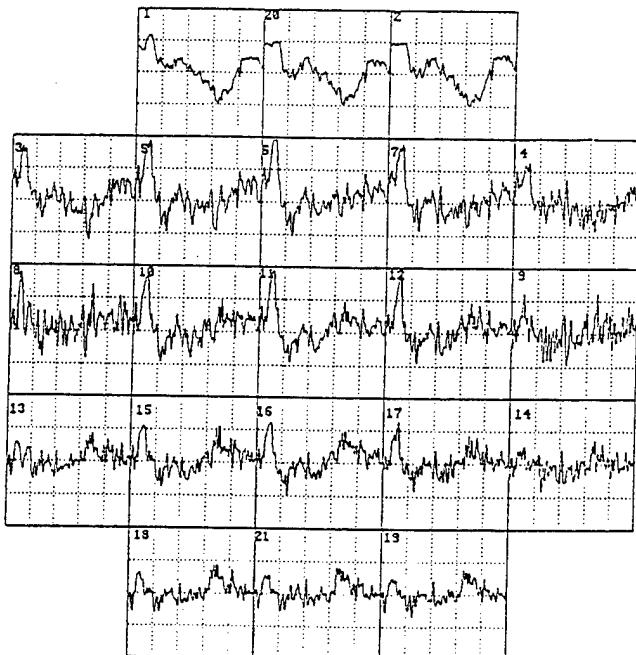


Figure B-5. P-300 waveforms collected from pilot 5 in the laboratory and two sets collected in the helicopter.

### In Laboratory



### In Helicopter #1



### In Helicopter #2

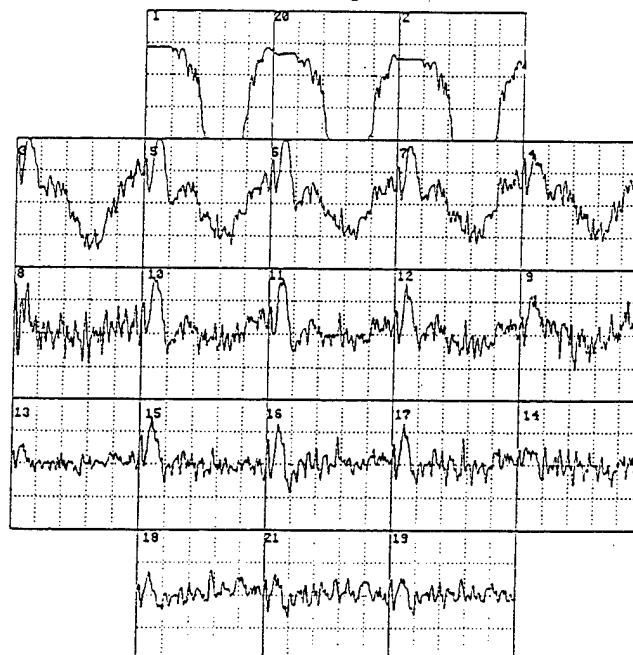
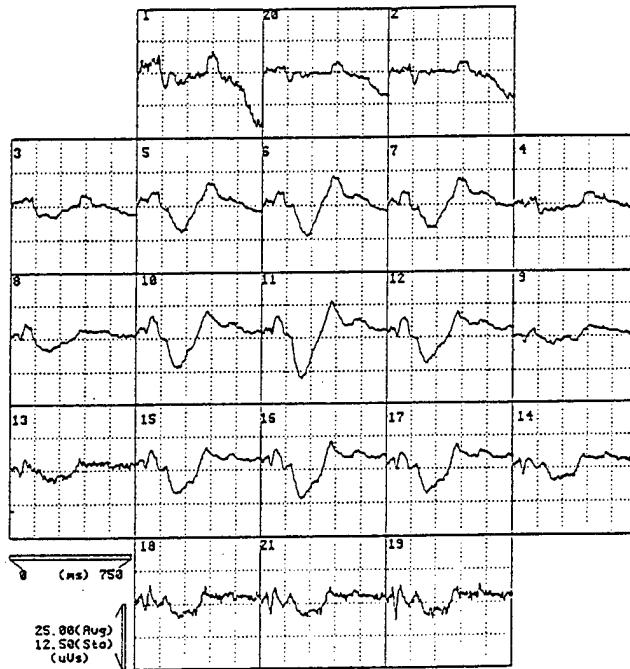
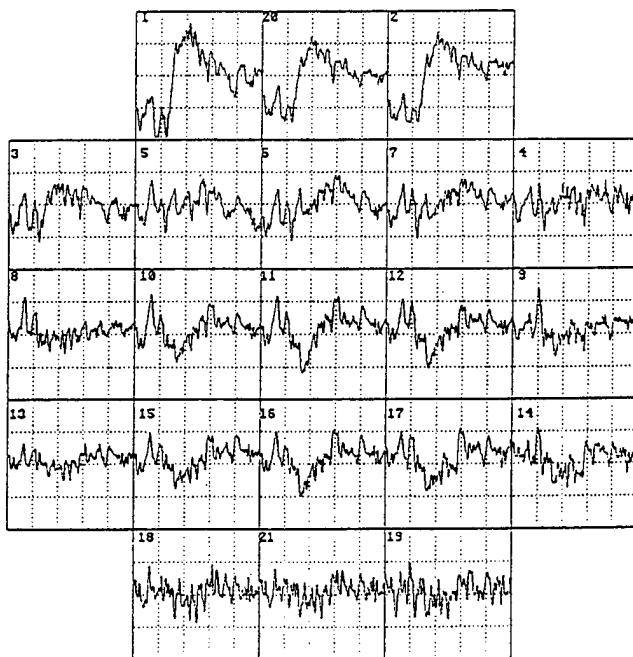


Figure B-6. P-300 waveforms collected from pilot 6 in the laboratory and two sets collected in the helicopter.

### In Laboratory



### In Helicopter #1



### In Helicopter #2

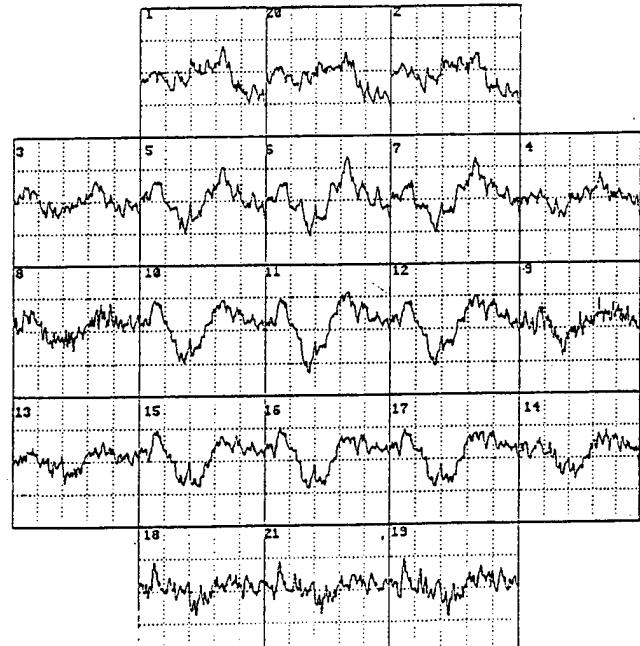
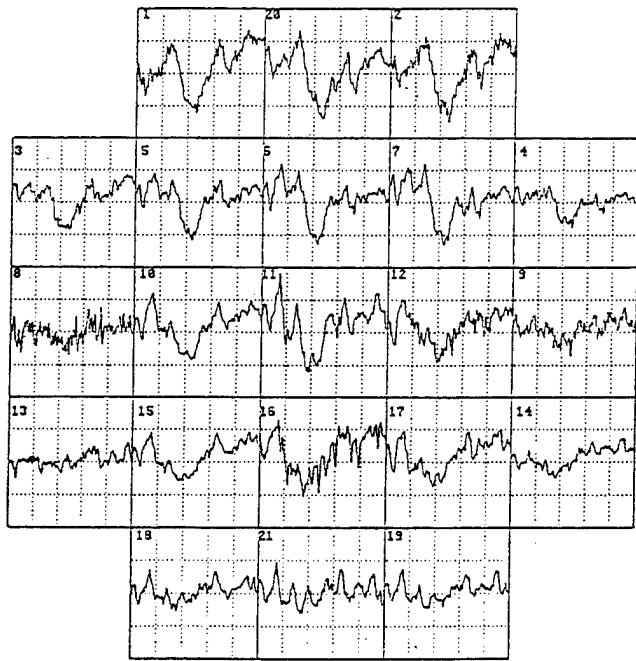


Figure B-7. P-300 waveforms collected from pilot 7 in the laboratory and two sets collected in the helicopter.

### In Laboratory



### In Helicopter #1



### In Helicopter #2

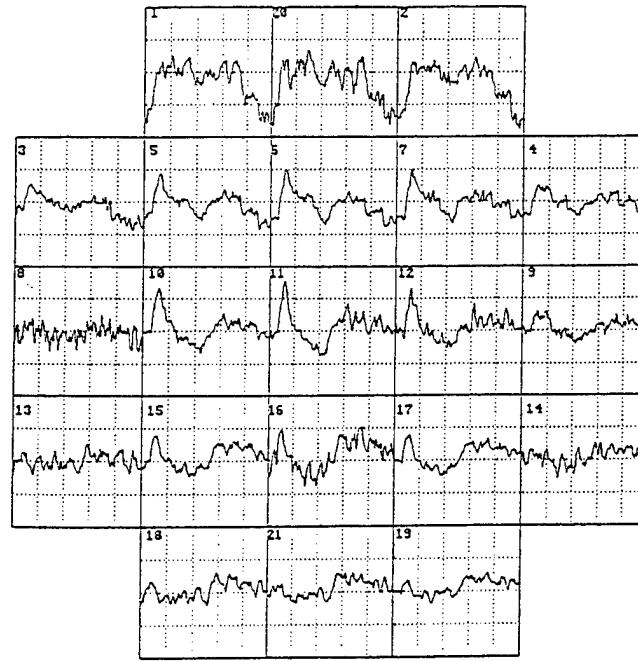
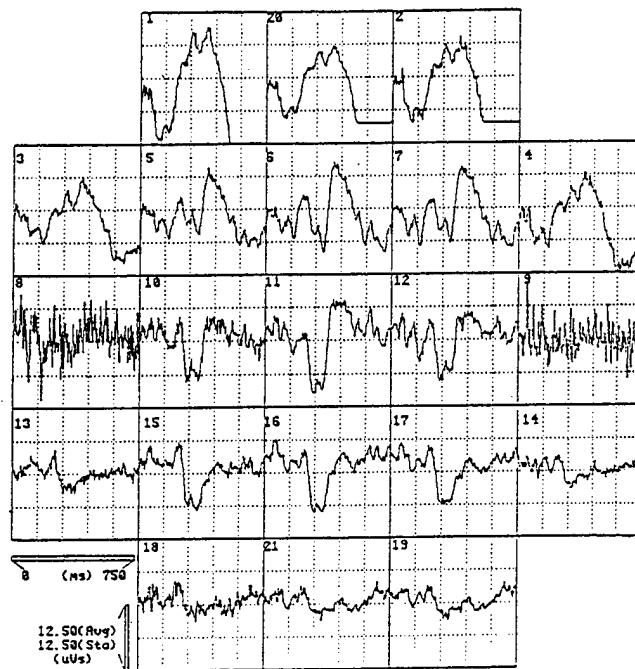
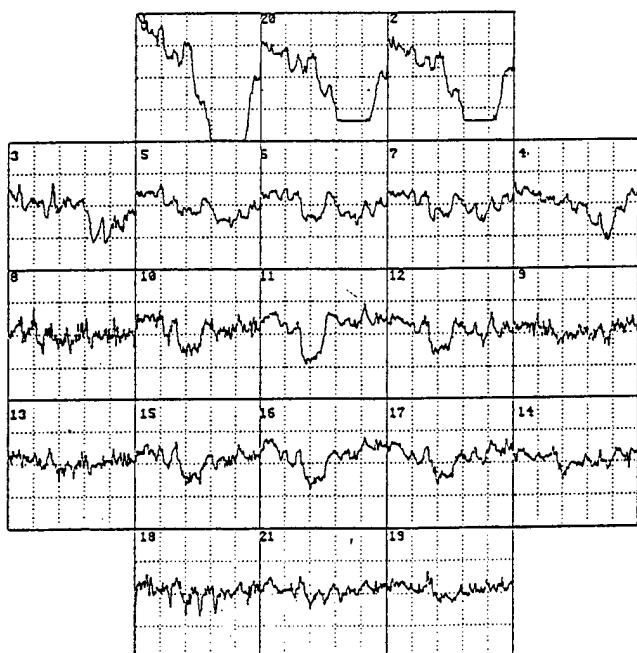


Figure B-8. P-300 waveforms collected from pilot 8 in the laboratory and two sets collected in the helicopter.

### In Laboratory



### In Helicopter #1



### In Helicopter #2

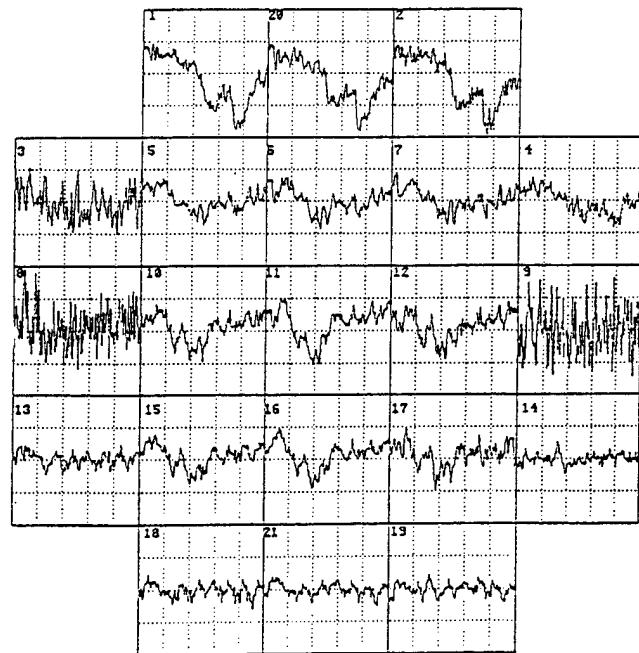
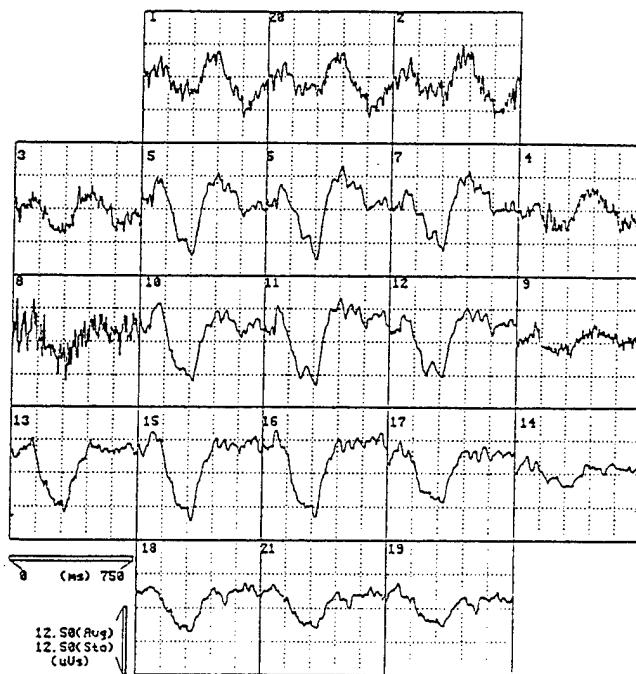


Figure B-9. P-300 waveforms collected from pilot 9 in the laboratory and two sets collected in the helicopter.

### In Laboratory



### In Helicopter #1



### In Helicopter #2

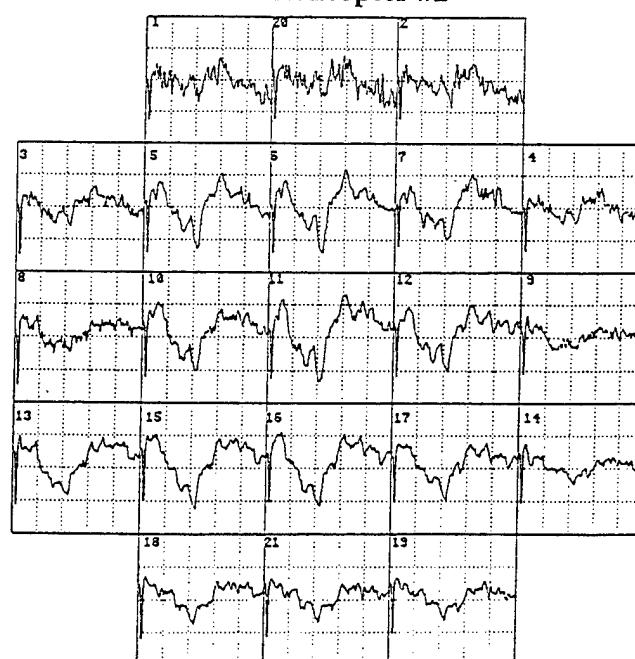
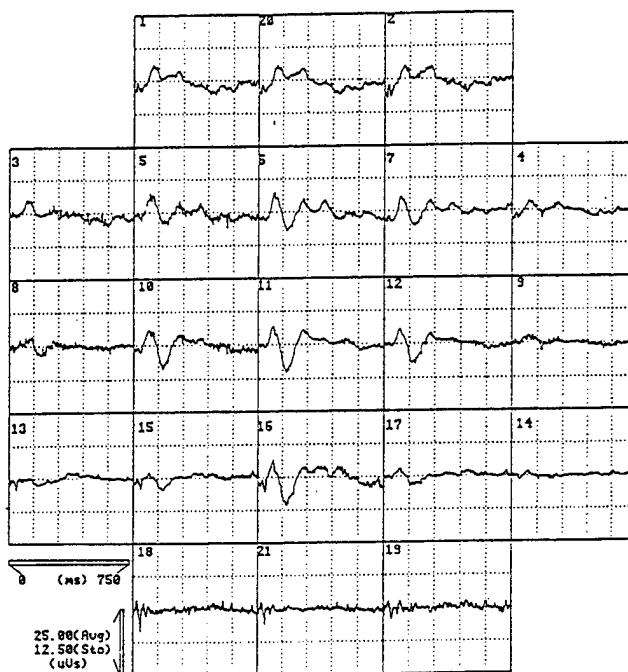
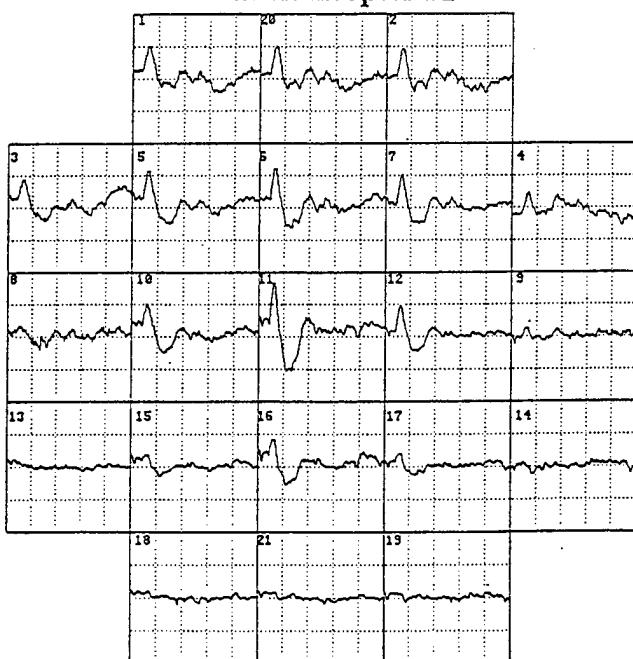


Figure B-10. P-300 waveforms collected from pilot 10 in the laboratory and two sets collected in the helicopter.

### In Laboratory



### In Helicopter #1



### In Helicopter #2

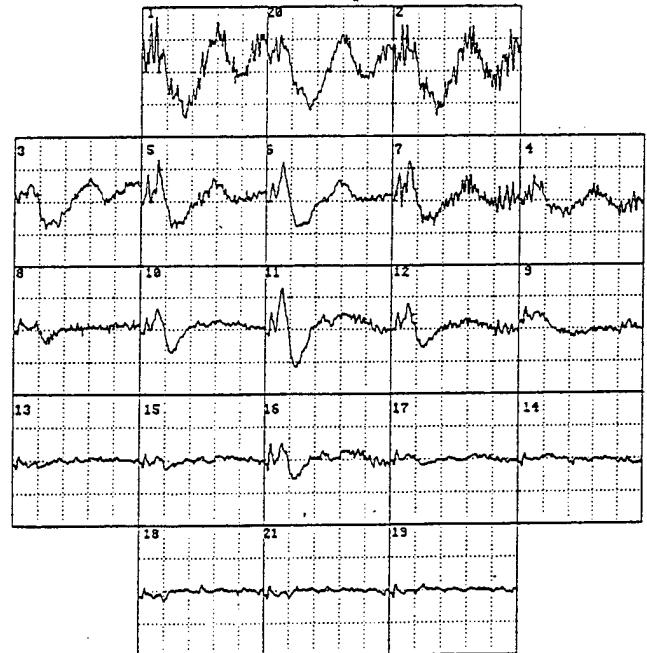
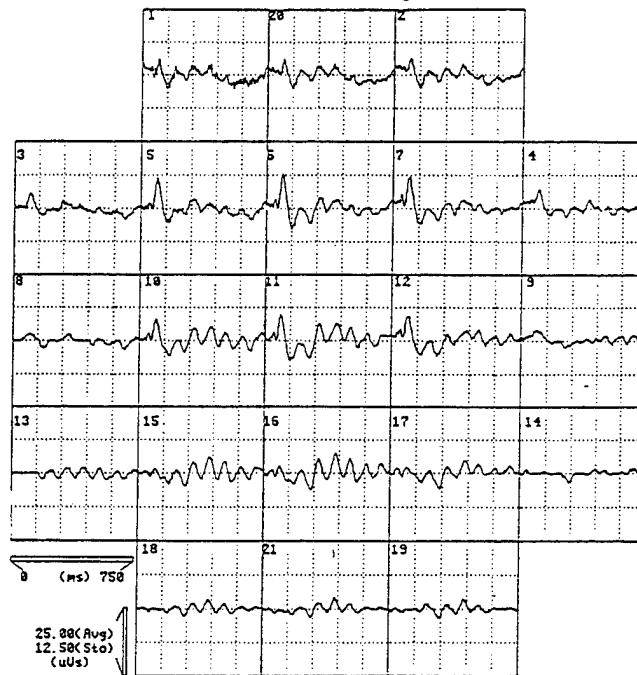
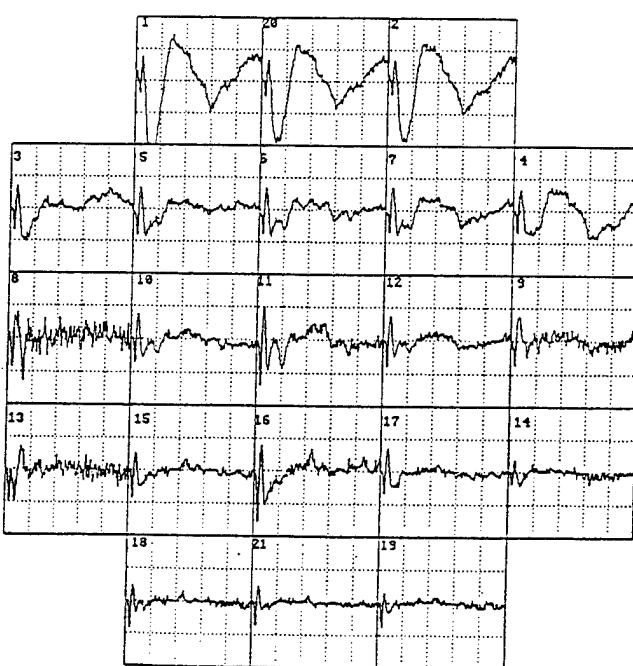


Figure B-11. P-300 waveforms collected from non-pilot 1 in the laboratory and two sets collected in the helicopter.

**In Laboratory**



**In Helicopter #1**



**In Helicopter #2**

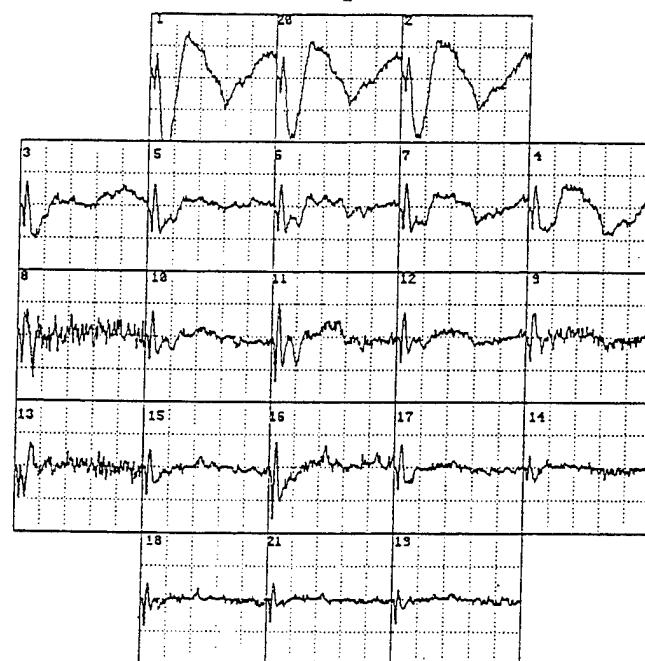
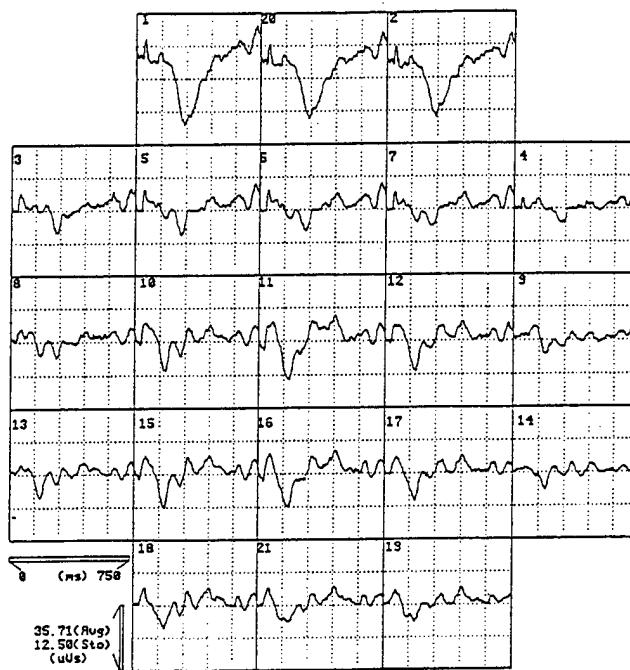
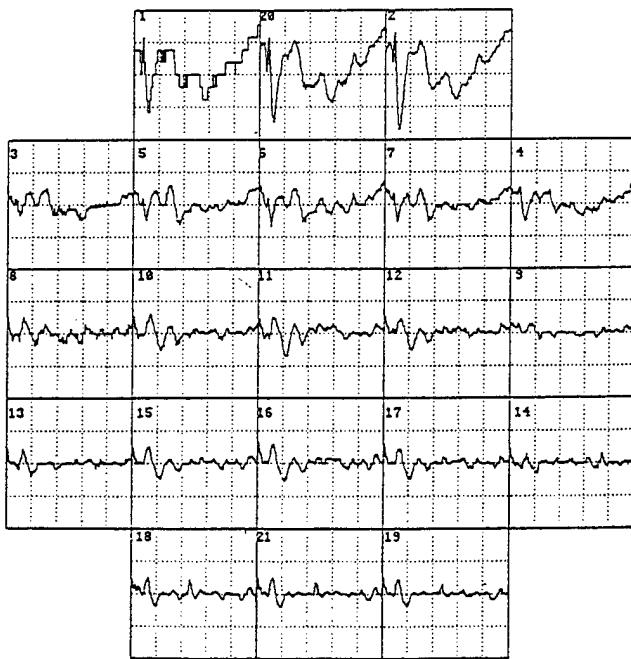


Figure B-12. P-300 waveforms collected from non-pilot 2 in the laboratory and two sets collected in the helicopter.

**In Laboratory**



**In Helicopter #1**



**In Helicopter #2**

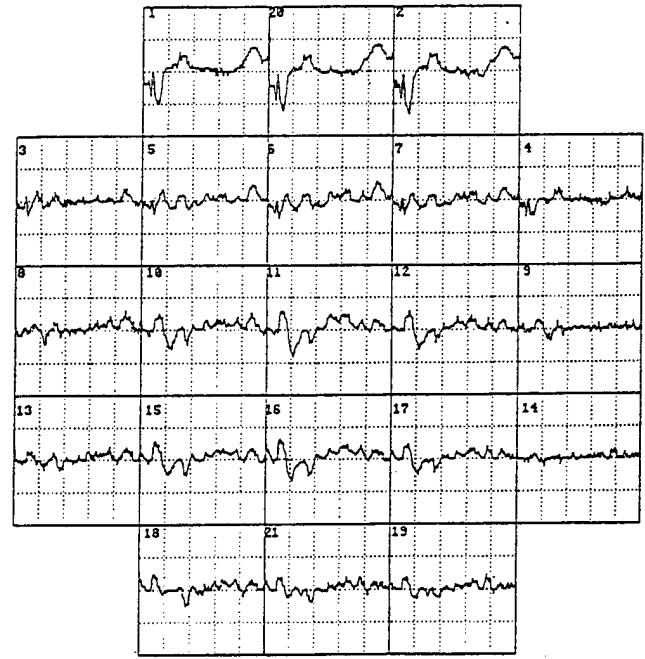
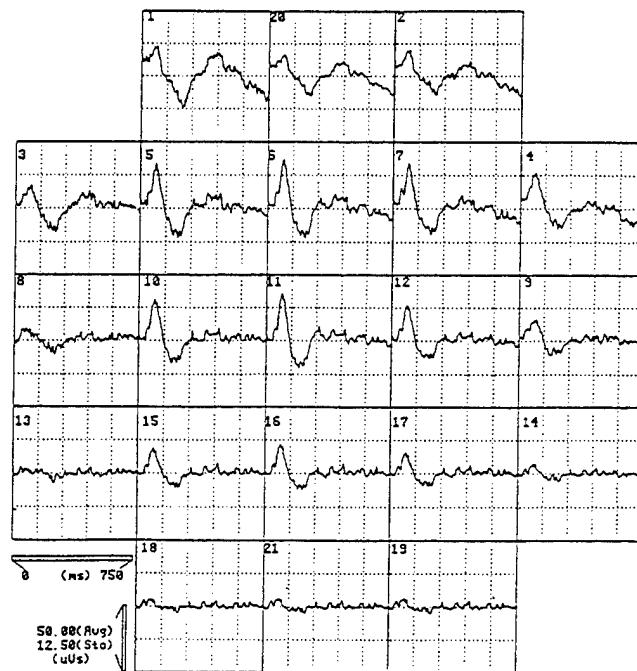
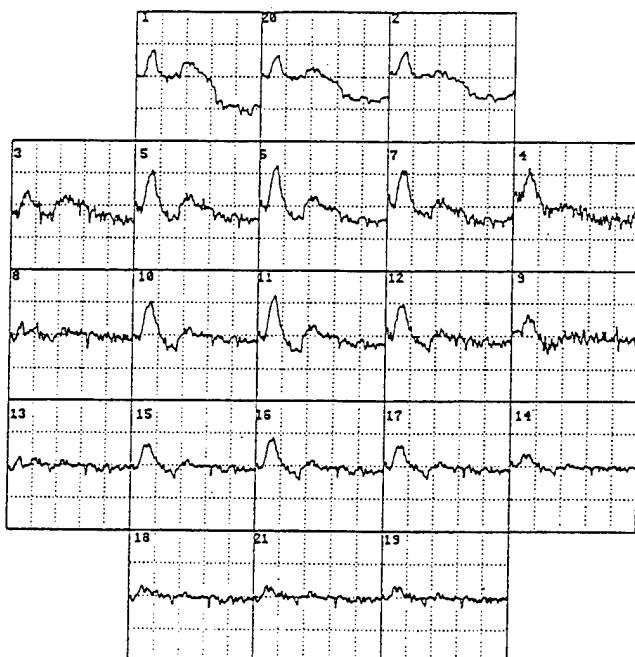


Figure B-13. P-300 waveforms collected from non-pilot 3 in the laboratory and two sets collected in the helicopter.

### In Laboratory



### In Helicopter #1



### In Helicopter #2

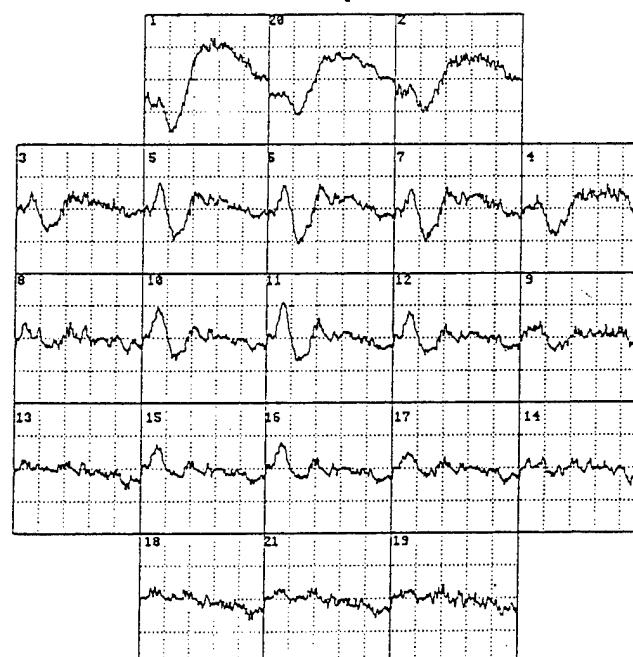
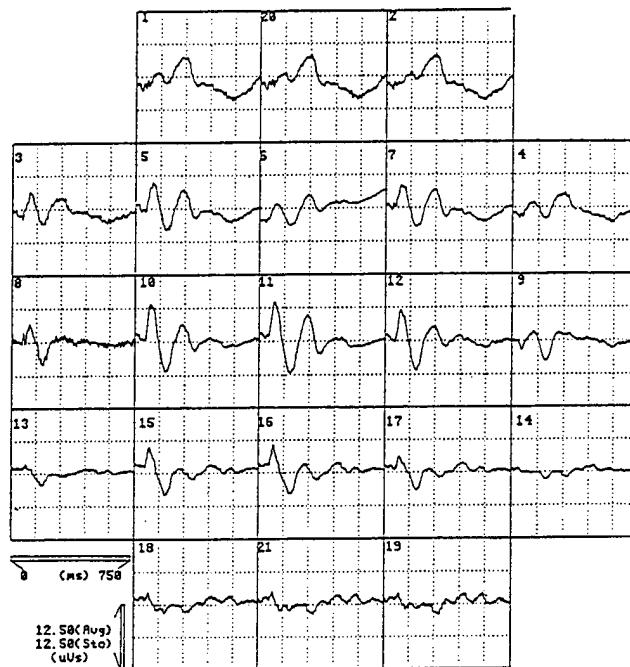
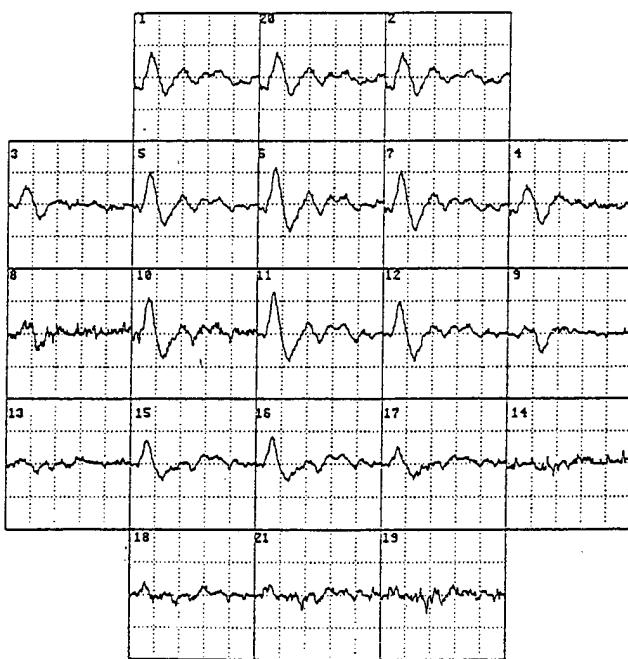


Figure B-14. P-300 waveforms collected from non-pilot 4 in the laboratory and two sets collected in the helicopter.

### In Laboratory



### In Helicopter #1



### In Helicopter #2

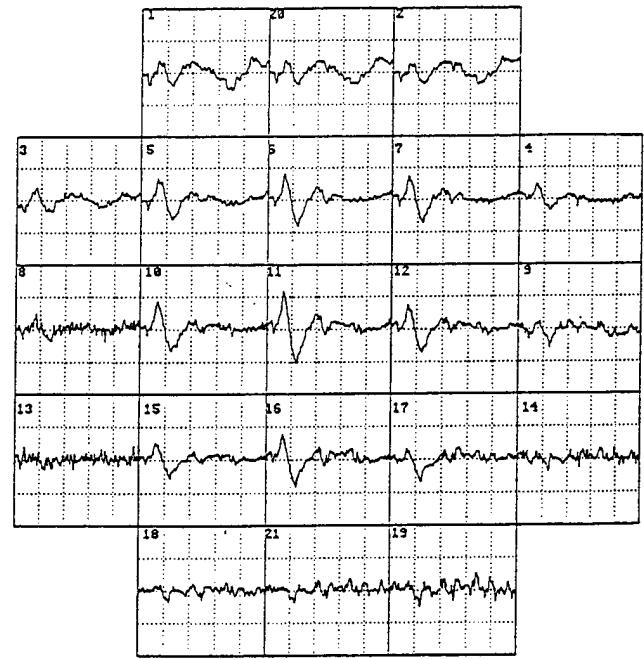
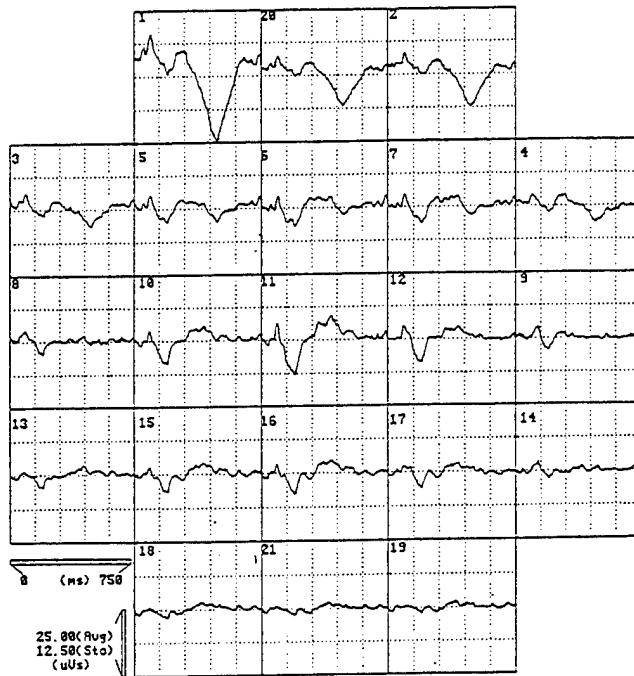
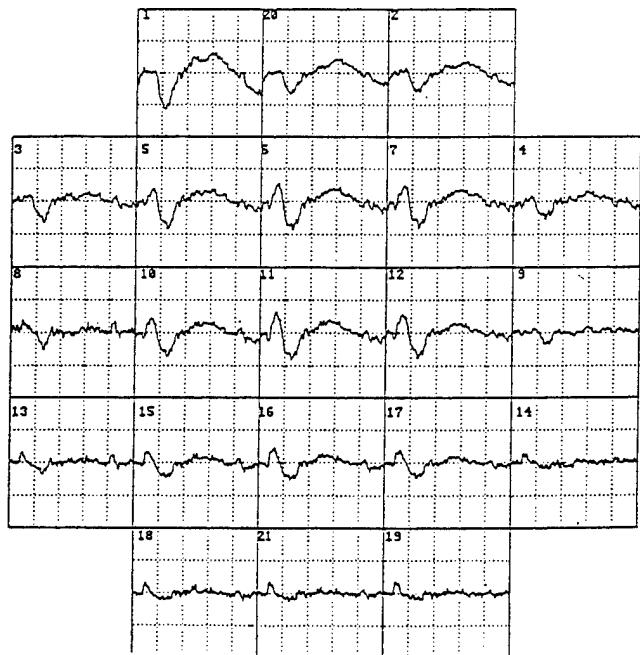


Figure B-15. P-300 waveforms collected from non-pilot 5 in the laboratory and two sets collected in the helicopter.

In Laboratory



In Helicopter #1



In Helicopter #2

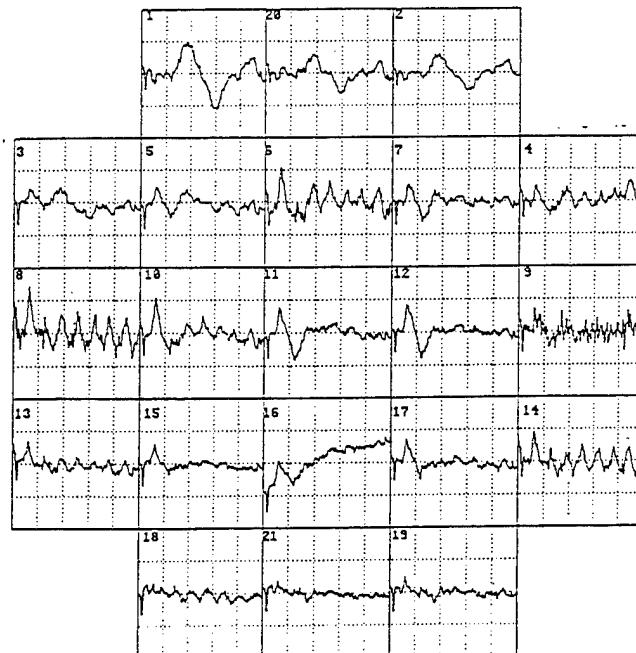
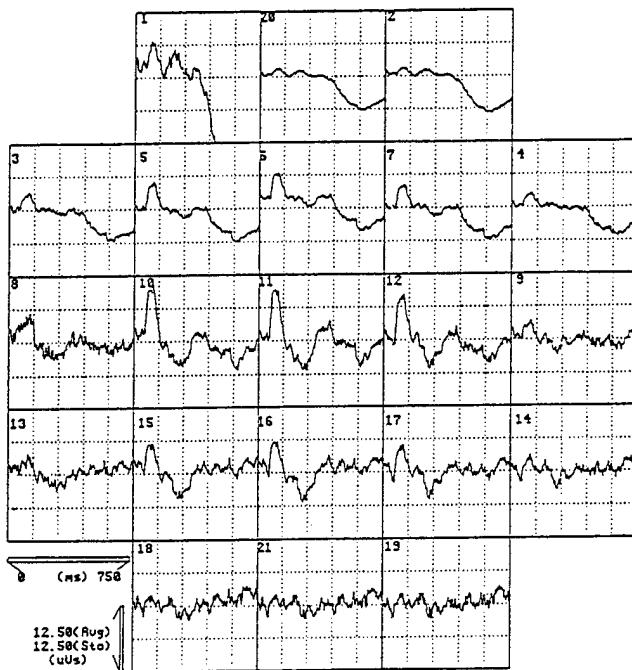
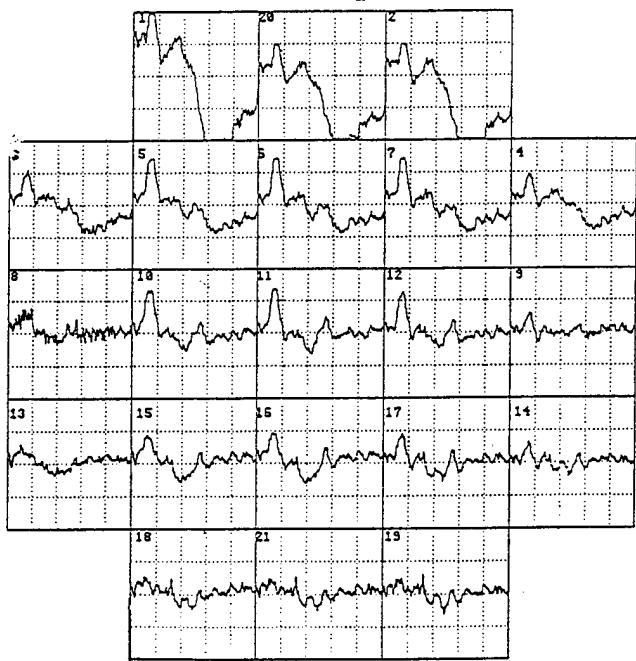


Figure B-16. P-300 waveforms collected from non-pilot 6 in the laboratory and two sets collected in the helicopter.

**In Laboratory**



**In Helicopter #1**



**In Helicopter #2**

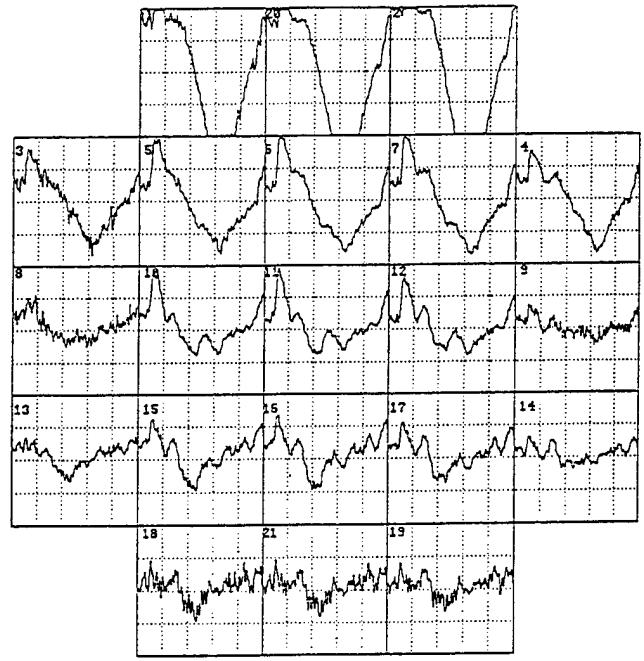
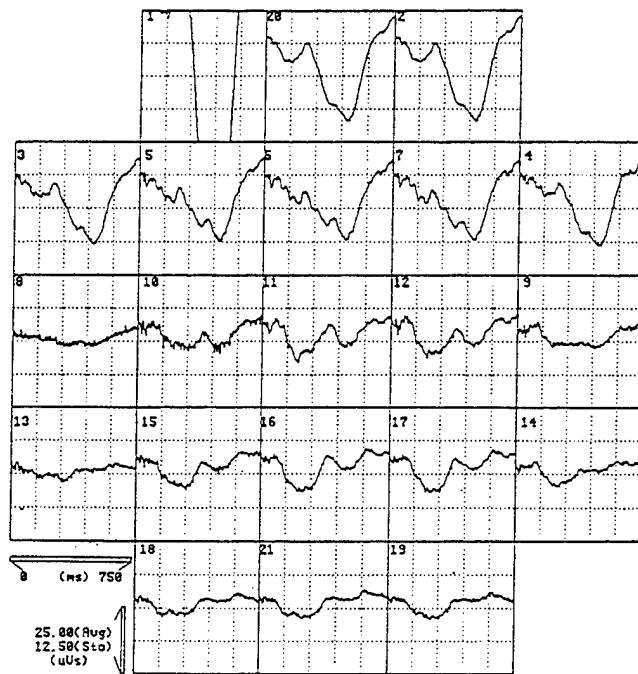
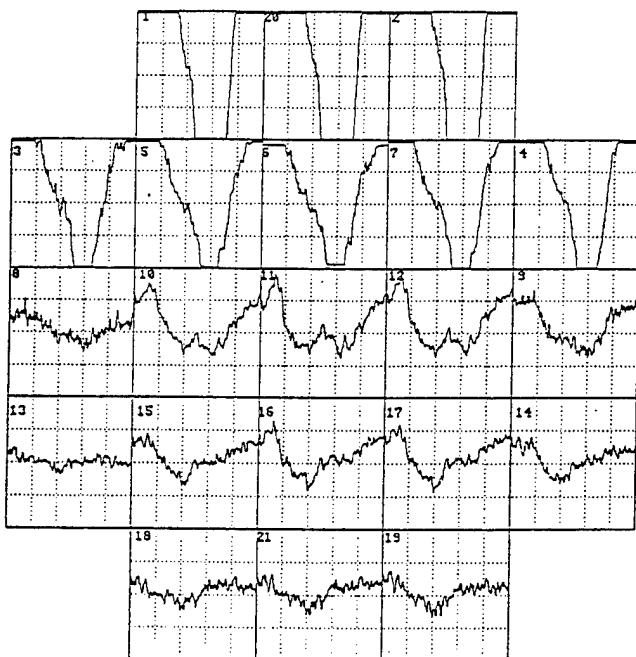


Figure B-17. P-300 waveforms collected from non-pilot 7 in the laboratory and two sets collected in the helicopter.

**In Laboratory**



**In Helicopter #1**



**In Helicopter #2**

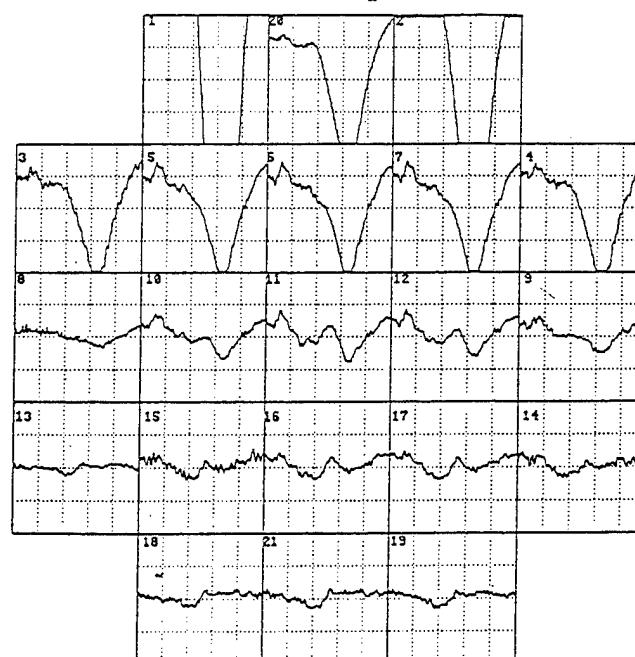
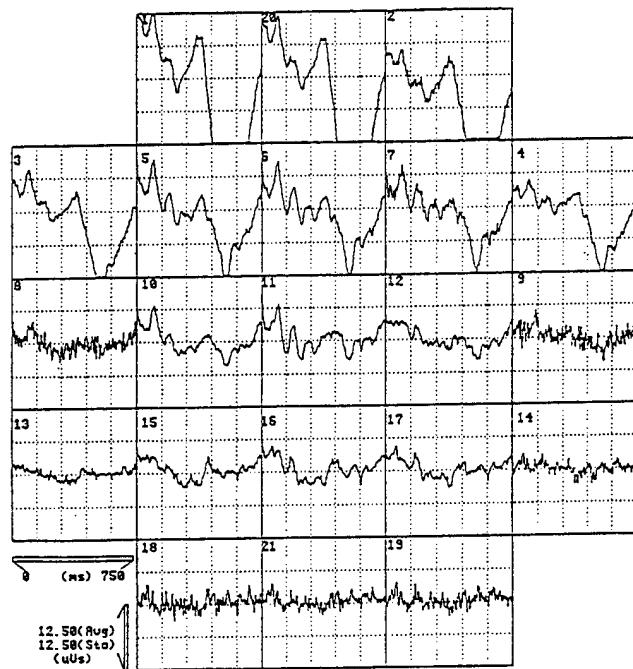
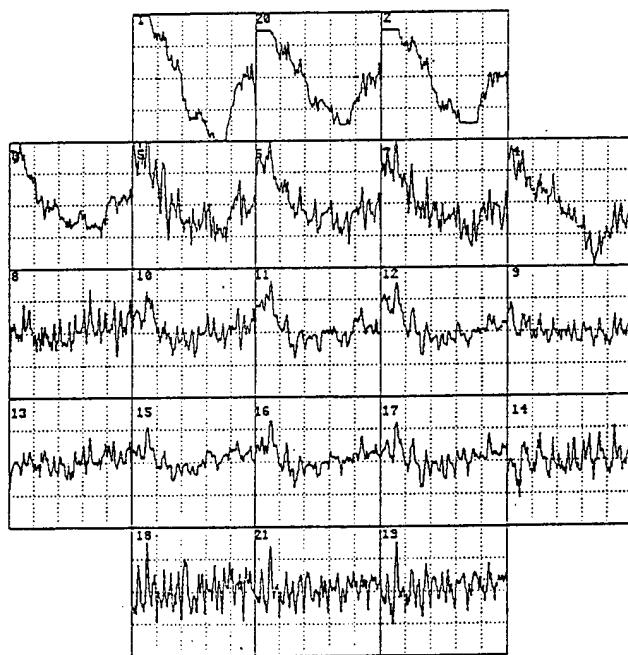


Figure B-18. P-300 waveforms collected from non-pilot 8 in the laboratory and two sets collected in the helicopter.

### In Laboratory



### In Helicopter #1



### In Helicopter #2

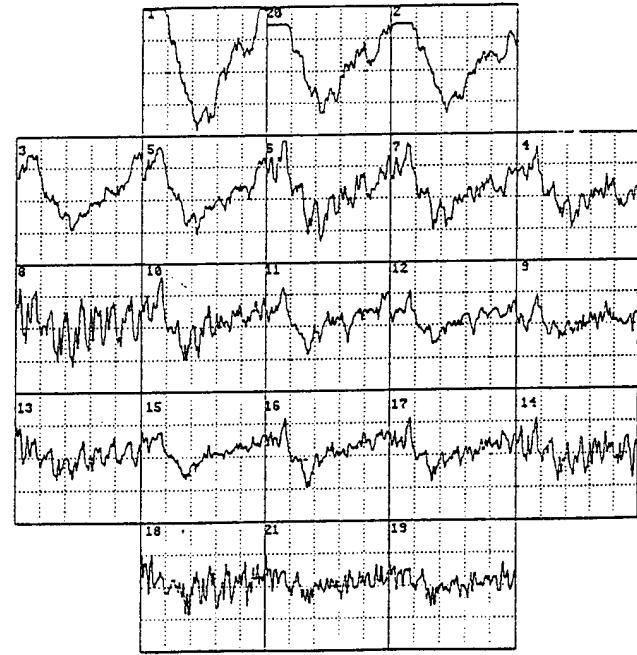
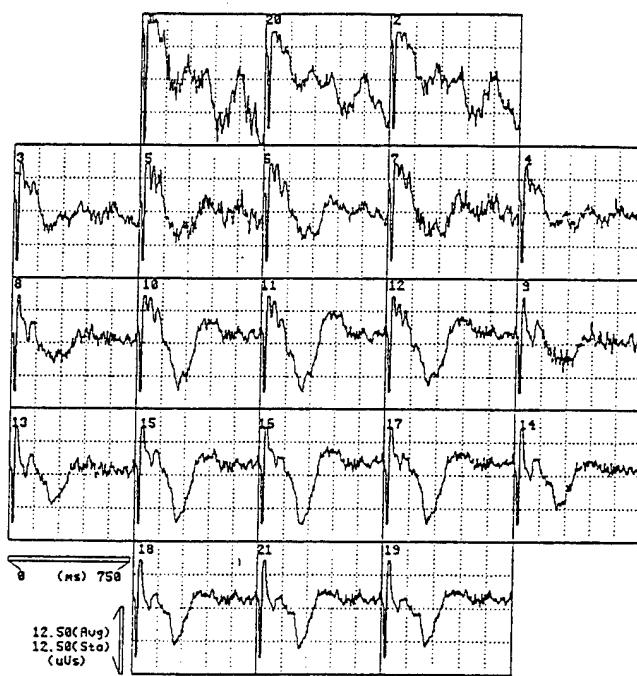
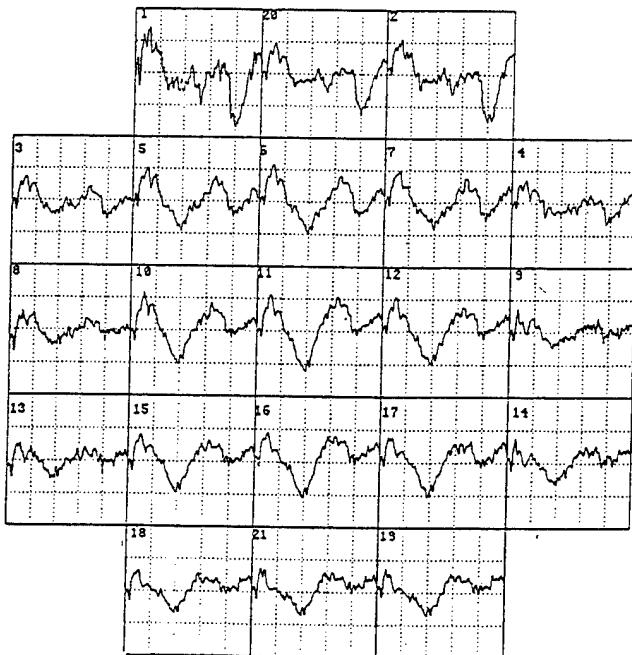


Figure B-19. P-300 waveforms collected from non-pilot 9 in the laboratory and two sets collected in the helicopter.

### In Laboratory



### In Helicopter #1



### In Helicopter #2

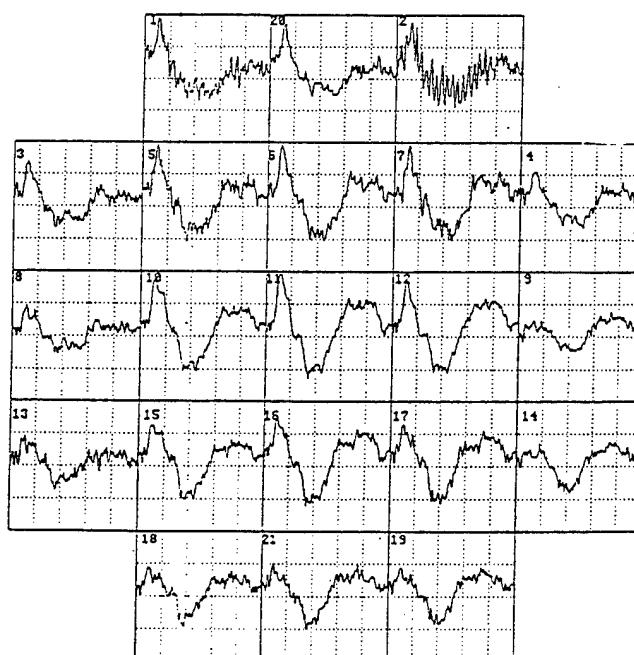
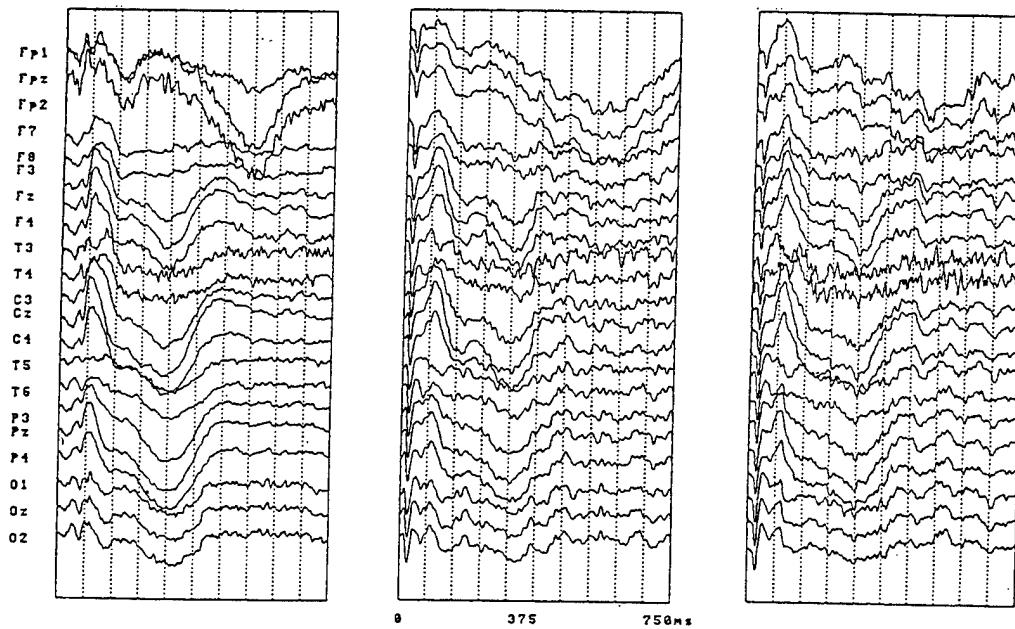


Figure B-20. P-300 waveforms collected from non-pilot 10 in the laboratory and two sets collected in the helicopter.

Part 2. Grand average P-300s for laboratory and in-flight conditions.

## P-300 Grand Averages

Pilots



Non Pilots

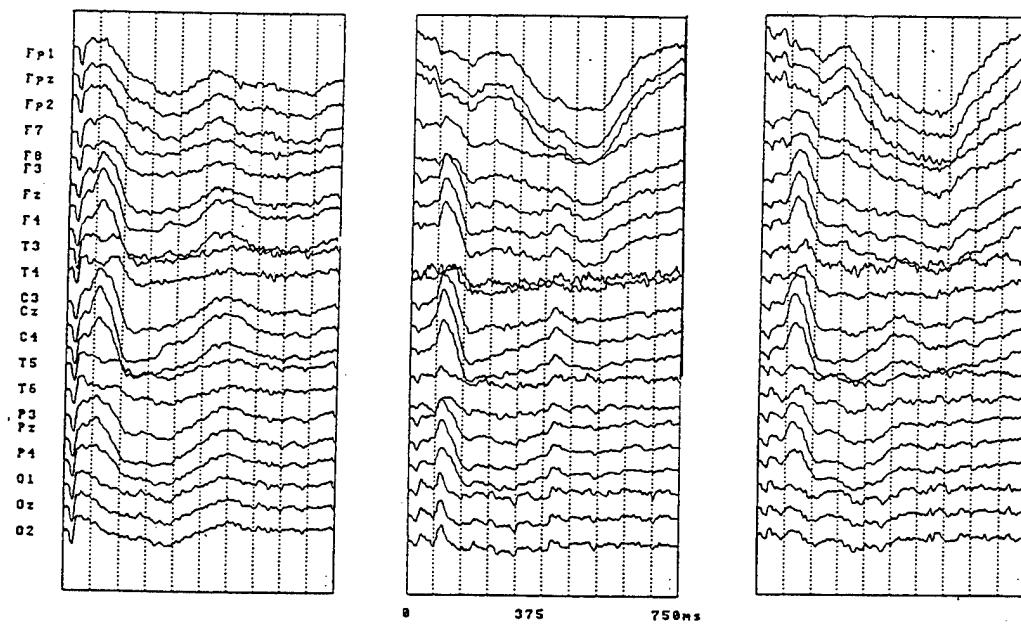


Figure B-21. In laboratory and in-flight P-300 grand averages for pilots and nonpilots.